The Geologic Occurrence Of Monazite

GEOLOGICAL SURVEY PROFESSIONAL PAPER 530

The Geologic Occurrence Of Monazite

By WILLIAM C. OVERSTREET

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A review of the distribution of monazite and of the geologic controls affecting the amount of thorium in monazite

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PLATES 1, 2. Map showing distribution of monazite in—
1. Asia, Australia, New Zealand, Antarctica, and the eastern part of Africa.
2. North America, South America, and the western part of Africa.

THE GEOLOGIC OCCURRENCE OF MONAZITE

By William C. Overstreet

ABSTRACT

The mineral monazite is a thorium-bearing anhydrous phosphate of the cerium earths. On the basis of 731 analyses, it contains from 0 to 31.50 percent of ThO_2 (thorium oxide) and averages 6 percent. This mineral is the major source for thorium. Monazite and bastnaesite, a fluocarbonate of the cerium earths, are the principal ores for the cerium group of the rare earths. In industry, thorium and the rare earths are needed in gas mantles, cores of carbon electrodes, optical glass, colored glass, ceramics, glazes, glass polishing, pyrophoric alloys, metallurgical processes, printing and dyeing, magnesium alloys, and radioactive energy applications.

The use of thorium for energy purposes in the 1940's led to political restrictions in the international traffic in monazite and to curtailment of publication of production data. Between 1880 and 1961 the world production of monazite, exclusive of Europe and the U.S.S.R., was at least 271,000 short tons. North Carolina was the earliest commercial source of monazite. In the United States monazite also has been mined in South Carolina, Florida, and Idaho. Most of the world output has come from Brazil, India, and the Republic of South Africa, but 12 other countries have produced the mineral; these countries include the Malagasy Republic, Mozambique, Nigeria, Republic of the Congo (Leopoldville), United Arab Republic, Ceylon, Federation of Malaya, Korea, Thailand, Republic of Indonesia, Australia, and Argentina.

Monazite is distributed throughout Africa in a wide variety of geologic environments. Most commonly it occurs as an accessory mineral in Precambrian gneisses, schists, and migmatites. Thorium-poor monazite forms concentrations in carbonatites and other alkalic rocks associated with volcanic calderas exposed in Kenya, Uganda, Rhodesia and Nyasaland, and the Republic of South Africa. Thorium-rich monazite is concentrated in quartz-apatite-monazite veins formed by metamorphic differentiation in the Malagasy Republic and the Republic of South Africa. The vein deposits in the Republic of South Africa were one of the world's most important commercial sources of monazite in the 1950's. Placers in Africa have been but little exploited for monazite. The principal placers mined are along the southeastern coast of the Malagasy Republic, the cassiterite deposits of Nigeria, and at the delta of the Nile in the United Arab Republic.

Monazite deposits in Asia include the world's largest known reserves, which are in the coastal deposits of India, and the world's most thorium-rich monazite deposit, which is mined in Ceylon. The resources of monazite in stream and beach placers of India, southeast Asia, and Korea seem to be immense. Successful commercial exploitation hinges on beneficiation of multimineral concentrates in which monazite is associated with ilmenite, rutile, cassiterite, wolframite, and gold.

Every State in Australia has been reported to have monazite, and the mineral has been found in New Zealand. Although abundant in the tin and tungsten placers of eastern Australia, monazite has been commercially unacceptable because it generally contains less than 2 percent of ThO_2. An annual byproduct output as great as several hundred tons of monazite having 6.6 percent ThO_2 was maintained from 1948 until at least 1961 at extensive zircon-rutile placers along the southeastern coast of Queensland and the northeastern coast of New South Wales. Monazite occurrences in New Zealand are not economic sources for the mineral.

The shores of the Antarctic Continent have been found to have ice-rafted grains of detrital monazite and glacially deposited boulders of igneous and metamorphic rocks containing accessory monazite. The occurrences seem to have no economic importance.

North America was the first important source of monazite in world commerce. Monazite was mined from fluvial placers in North Carolina and South Carolina from 1887 through 1917, but after 1895 Brazilian beach deposits became the main source for the mineral. Other exploited sources in North America are beach placers in Florida and stream deposits in Idaho. Large resources of monazite have been discovered in fossil placers that range in age from Precambrian to Late Cretaceous. Very large low-grade resources of monazite doubtless exist with ilmenite in the sedimentary rocks of the Atlantic and Gulf Coastal Plains and in offshore deposits of the Southeastern United States and the gulf coast of Mexico. Little monazite has been found in the northern part of the North American Continent.

Marine beaches and elevated bars along the southern coast of Brazil were the world's main source of commercial monazite from 1895 through 1913, and a moderate extension of these beaches and bars has been found in Uruguay. The Brazilian ilmenite-monazite placers still constitute one of the larger known resources of monazite in the world, but new discoveries in Africa, Asia, Australia, and North America lessen their international importance. Stream placers in the interior of Brazil are virtually unexplored; they may constitute an immense resource.

Monazite is widely distributed throughout the world as a minor accessory mineral in intermediate- and high-rank metamorphic rocks derived from argillaceous sediments. Monazite is less commonly present in metamorphic rocks of like facies formed from arenaceous sediments and is rarely present in metamorphosed calcareous sedimentary rocks. The mineral is especially common in argillaceous schists, gneisses, and migmatites of the upper subfacies of the amphibolite facies and of the granulite facies. Monazite occurs in magmatic rocks ranging in composition from diorite to muscovite granite, and in associated pegmatite, greisen, and vein quartz. In

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this group it is most commonly observed in biotite quartz monzonite, two-mica granite, muscovite granite, and cassiterite-bearing granite. Monazite is reported to be present in only a few places in quartz porphyry, aplite, or felsite, and has not been found in silicic lava. Monazite rarely occurs in syenite, except locally in nepheline syenite and syenite pegmatite, but is commonly abundant in carbonatite and related alkalic volcanic rocks and dikes. Monazite does not occur in mafic lavas or plutonic rocks but has been observed at one locality in mafic dikes and breccia of uncertain origin. Monazite forms in a wide variety of veins, from simple cleft fillings of the Alpine type through mesothermal quartz veins and alteration zones to hypothermal tungsten- and tin-bearing quartz veins and alteration zones. Locally it occurs in vugs and druses. Where monazite is an accessory mineral, it rarely makes up more than a few hundredths of 1 percent of the host rock. Several extraordinary enrichments of monazite are known in plutonic terrane where thorium-rich monazite is concentrated in veins by metamorphic differentiation. Other important concentrations in crystalline rocks are hydrothermal deposits of low-thorium oxide monazite in marble and primary volcanic or postvolcanic replacement deposits in carbonatite and alkalic rocks.

Monazite eroded from crystalline rocks is transported by streams and accumulates in sedimentary rocks. Locally the processes of erosion and transportation may be varied and complex, and detrital monazite may have gone through several cycles before arriving at its present site. Processes of glacial and wind erosion and transport have released, moved, and concentrated monazite, but the most effective agents are those related to rock weathering, fluvial transport, and accumulation of eroded material on beaches. Monazite is concentrated at the site of weathering, in streams, and on beaches, but the richest and largest concentrations are the beach deposits. Because rock weathering is most effective in warm humid environments where chemical weathering exceeds the rate of erosion, the greatest present placers are along beaches in tropical and subtropical regions where monazite from the weathered rocks received preliminary concentration in coastal plain sediments and where these sediments are being eroded by the ocean.

Monazite has a restricted occurrence in crystalline and sedimentary rocks. In crystalline rocks its presence can be related to conditions of temperature and pressure during metamorphic or magmatic crystallization. In metamorphic rocks the temperature and pressure conditions are shown by the grade of regional metamorphism. In magmatic rocks they are indicated by the composition of the rock and the degree of alteration of the wallrocks. In sedimentary rocks the occurrence of monazite is controlled by mechanical processes.

Monazite in the epizone is characteristically of hydrothermal origin in veins, vugs, and disseminations associated with shallow late-tectonic or posttectonic plutons of granitic rocks. It may be present in highly differentiated alkalic volcanic rocks but is rarely found in epizonal slate, phyllite, or schist. Monazite formed in the epizone, except in cassiterite-bearing granites, tends to be lean in thorium. Monazite from epizonal plutons tends to have 200–800 percent more thorium than monazite from the wallrocks.

Monazite in the mesozone is typically of metamorphic or magmatic origin. It is more abundant in granitic rocks than in metasedimentary rocks, but both rocks contain more monazite than their equivalents in the epizone. Monazite from the mesozone has more thorium than that from the epizone, and the amount of thorium in monazite from mesozonal magmatic rocks is about 50–200 percent greater than the amount of thorium in monazite from metasedimentary wallrocks.

Monazite in the katazone is about equally abundant in metasedimentary and magmatic rocks and is much more common in both kinds of rock than it is in the mesozone or epizone. The amount of thorium in monazite from granitic rocks in the katazone is generally only 10–20 percent greater than the amount in monazite from metasedimentary rocks. An enrichment in thorium takes place in monazite formed in pegmatites in the katazone, and such pegmatites contain the most thorium-rich monazite known.

Monazite in metamorphic rocks participates in a metamorphic cycle whose chief feature is the loss of detrital monazite and the formation of authigenic metamorphic monazite. Detrital monazite is unstable in early stages of regional metamorphism. It breaks down and shares its components with other minerals. As the grade of regional metamorphism increases, an environment is reached in which monazite becomes stable. Metamorphic monazite begins to form at a few centers of crystallization; these centers multiply with increasing grade of metamorphism until the rock finally contains far more metamorphic monazite than it originally had detrital monazite. The main sources for the metamorphic monazite are thorium, rare earths, and phosphorus held by other detrital components of the original sediment, chiefly hydrolyzates, clays, mica, and apatite.

Many features of monazite in paraschists and paragneisses show that it is of metamorphic origin. Chief among them are direct relation between grade of metamorphism and amount of monazite in the rock; inverse relation between amount of monazite in metamorphic rock and grain size of original sediment; lack of similarity between the range in grain size of particles of monazite in paraschists and paragneisses and the probable size range in the original sedimentary rock; correlation between physical properties of monazite and metamorphic grade of host rock; inclusions in monazite identical with metamorphic minerals in the host rock; intergrowths between monazite and metamorphic minerals in the host rock; a reverse relation between monazite, allanite, and other thorium-bearing minerals in metamorphic rocks; and a direct relation between the amount of thorium in monazite and the grade of regional metamorphism. The last feature is particularly convincing: the average amount of thorium oxide in monazite from rocks of the greenschist facies is 0.4 percent; from rocks of the albite-epidote-amphibolite facies, 3 percent; from rocks of the amphibolite facies, 4.9 percent; and from rocks of the granulite facies, 8.9 percent.

The presence and composition of monazite formed in magmatic rocks are controlled by the degree of differentiation and spatial and temporal relations of the host. Differentiation under plutonic conditions gives granitic masses of batholithic dimension in which monazite is a minor accessory mineral, but large volumes of monazite-rich rocks are not formed. Differentiation of alkalic rocks forms large concentrations of thorium-poor monazite in carbonatite. Fractionation during crystallization produces thorium-rich monazite in pegmatites. Among magmatic rocks, monazite is most common in granitic rocks, particularly synkinematic granites in the upper subfacies of the amphibolite facies and in the granulite facies. An increase in the average amount of thorium is noted in monazite from plutonic granitic rocks. If the metamorphic facies of the wallrocks is regarded as an index of plutonism, the average amount of thorium in monazite from granites in different metamorphic facies is as follows: Greenschist facies, about 0.5 percent of ThO_2; lower and middle subfacies of the amphibolite facies, 4.2 percent; middle and upper subfacies of the amphibolite facies, 6 percent; granulite facies, about 8 percent.

Monazite from pegmatites shows no detectable relation to the grade of metamorphism of the wallrocks, but pegmatite itself is rare in metasedimentary rocks of lower grade than the amphibolite facies. Fractionation of the fluid that yields the various rock types of complex pegmatites may well be a major control of the composition of the monazite.

The average amount of thorium in monazite from veins increases from the epithermal to the hypothermal stages: 0.2 percent of ThO_2 in monazite from epithermal veins, 1.4 percent in monazite from mesothermal veins, and 3.4 percent in monazite from hypothermal veins.

Geologic control of monazite in sedimentary rocks is related to the fact that monazite is stable in the weathering profile and to the fact that it has a greater specific gravity than ordinary rock-forming minerals. The sedimentary cycle of monazite begins with its release from host materials and ends with the onset of regional metamorphism. The geologic processes are dominated by mechanical agencies except at the outset when chemical weathering is active. Mechanical activity in the sedimentary cycle tends to concentrate monazite in placers. The richest monazite placers are formed by a succession of sedimentary cycles; for example, the monazite-enriched coastal plain deposits have been further concentrated through wave erosion and resorting on ocean beaches. Fossil placers of great antiquity and richness testify that intrastratal solution does not destroy old placers.

The amount of thorium in monazite from placers varies from place to place in the world and depends upon the kind of crystalline rocks from which the monazite originally came. In general, the more plutonic the source, the more thorium the placer monazite contains. Because of mechanical blending during transport and deposition, bulk samples of monazite from various parts of a placer tend to have a more uniform composition than bulk samples of monazite from various parts of a mass of crystalline rock.

Monazite is more common, and tends to have more thorium, in crystalline rocks in Precambrian terrane than in areas underlain by younger crystalline rocks. Geologic age, however, is only an indirect factor, because regions occupied by Precambrian rocks contain a greater proportion of plutonic rocks than younger parts of the earth's crust. Nonplutonic Precambrian rocks or rocks otherwise petrologically unfavorable as a host are as lean in or as devoid of monazite as similar but geologically younger rocks; conversely, petrologically favorable rocks of Paleozoic or younger age are as rich in accessory monazite as similar Precambrian rocks.

INTRODUCTION

PURPOSE AND SCOPE OF REPORT

In this report, data on the geographic distribution, mode of geologic occurrence, composition, and commercial production of monazite are compiled from the literature. The report shows how the amount of thorium in monazite varies according to the origin of the monazite and describes the geologic cycles of monazite. In scope the report covers monazite occurrences throughout the world exclusive of Europe and the U.S.S.R. The few occurrences in Europe are, however, the subject of an extensive literature—more than 200 articles in 15 languages as of 1958—and the available reports on monazite in Russia, some of which are scientifically very important, numbered at least 118 by 1958.

For each of the areas discussed, an effort has been made to give the date of the local discovery of monazite and to cite reports between the discovery date and 1958. For some areas it has been possible to bring the review up to 1963.

The area discussions are arranged alphabetically by continent and by country under each continent. Smaller political units in some large countries are also discussed alphabetically. Within a country the text generally follows geologic mode of occurrence in the following order: Crystalline rocks, sedimentary rocks, stream deposits, and beach deposits. In important areas a given mode of occurrence may be further subdivided geologically or geographically. A particular mode of occurrence generally is discussed in chronologic sequence.

Geographic names are used as they were known on January 1, 1962. The spelling accords with usage of the U.S. Board on Geographic Names where decisions are available. For clarity, some recommended names are followed in parentheses by the spelling found in the article cited. Place names for which recommended spellings are unavailable are given as they were spelled in the original article.

Many old analyses are quoted in which the symbol Di is used for didymium. Didymium is unseparated neodymium (Nd) and praseodymium (Pr). The symbol Di is no longer employed in chemistry but has been retained here to show what the analyst originally reported.

The stratigraphic nomenclature is that of the published sources and does not necessarily conform to that of the U.S. Geological Survey.

ACKNOWLEDGMENTS

Many analyses and reports of monazite are scattered in the literature. In large part they are in such obscure sources that they were virtually lost until the 1950's when Margaret Cooper and her coworkers in the U.S. Geological Survey and U.S. Atomic Energy Commission completed an extensive bibliography of uranium and thorium (Cooper, 1953a, b, 1954, 1955, 1958). Through this bibliography and the continuing aid of Miss Cooper, it became possible to recover the many reports and to review the literature on monazite in a practicable length of time. It is a pleasure to acknowledge the help Miss Cooper's work has been to the preparation of this report.

Acknowledgment is also made of the aid received from Amos M. White of the U.S. Geological Survey in searching the South American literature, particularly that of Brazil.

DESCRIPTION OF MONAZITE

DISCOVERY, SYNONYMY, AND SYNTHESIS

The mineral monazite, an anhydrous phosphate of the cerium group of the rare earths, was named by Breithaupt (1829, p. 301). Breithaupt selected the name from a Greek verb meaning "to be solitary" in recognition of the rarity of the mineral at the site of its discovery near Miask in the Ilmen Mountains of Russia. Other names by which it has been known are turnerite (Levy, 1823), mengite (Brooke, 1831, p. 189), edwardsite (Shepard, 1837a, p. 163), eremite (Shepard, 1837b), kryptolith (Wöhler, 1846, p. 268), monazitoïd (Hermann, 1847a, p. 28–29), phospho-cerite (Watts, 1849, p. 131), urdit (Forbes and Dahll, 1855, p. 226), korarfveite (Radominski, 1874, p. 766), and erikite (Fleischer, 1959). The name turnerite was actually proposed earlier than monazite, but because turnerite was not as well described as monazite, the name monazite, according to Frondel (1958, p. 150), was retained for the mineral after the two were found to be the same by J. D. Dana (1866) and Des Cloizeaux (1873).

Long fragile prismatic crystals of monazite were formed artificially in 1875 by Radominski (1875, p. 305), who fused mixtures of cerium phosphate and cerium chloride. The crystals thus formed were as much as 0.75 inch long and resembled the natural mineral. Synthetic monazite was also produced through fusion methods at temperatures of 1,400°C by Karkhanavala (1956). Dry-fusion syntheses of monazite, however, are of academic interest, as natural monazite is formed in environments in which water is free to move. The hydrothermal synthesis of monazite is of more petrogenic interest. Anthony (1957) produced monazite in bombs from mixtures of dried cerium hydroxide gel and phosphoric acid at temperatures as low as 200°C, and Carron, Naeser, Rose, and Hildebrand (1958, p. 255–257) succeeded in synthesizing monazite from aqueous solutions of cerous chloride and phosphoric acid by fractional phosphate precipitation of pairs of rare-earth elements at a temperature of 300°C and a pressure of about 90 atmospheres. Attempts by Carron, Naeser, Rose, and Hildebrand to form monazite at temperatures between 100° and 250°C were unsuccessful.

PHYSICAL PROPERTIES

Most monazite is various shades of yellow. Honey yellow to golden yellow and also shades of transparent pale yellow are commonly mentioned in descriptions of detrital monazite from stream and beach placers and in descriptions of accessory monazite from granulite and gneiss. Shades of yellowish brown, brown, reddish brown, red, yellowish green, green, and greenish brown are locally common in detrital monazite from streams and lakes and in accessory monazite in schist, gneiss, granite, and, particularly, pegmatite. Pale-orange-yellow to yellowish-gray, white, gray, or nearly colorless monazite is rare, but monazite having these colors has been found in veins and vugs. Black monazite, apparently owing its color to carbon, has been reported from pegmatite in Canada, a stream in Korea, and the beaches of Taiwan. Other than the possible relation of black to the presence of carbon, no chemical basis is known for the color of natural monazite. The streak of monazite is white, very pale yellow, or very pale brown.

Monazite is transparent to subtransparent in small grains, but superficial alteration may render it opaque. Its luster is resinous to vitreous and is more brilliant in transparent grains than in subtransparent ones. Earthy monazite has been observed (Rose and others, 1958, p. 995).

Monazite is brittle. It is commonly modified by conchoidal or uneven fractures. Its hardness is 5 to 5½ on the Mohs scale; that is, it is as hard as or slightly harder than apatite but not as hard as orthoclase. Rinds of superficially altered grains are softer than apatite.

The specific gravity of virtually pure (Ce, La) PO_4 is 5.15 ± 0.05 (Frondel, 1958, p. 157). Differences in the chemical composition of monazite cause the specific gravity to range from 4.6 to 5.47. Theoretically, an increase in the amount of thorium in monazite is accompanied by an increase in specific gravity (Hermann, 1847b, p. 22). By actual analysis this relation has been difficult to demonstrate because the material accepted as monazite generally has not been pure; reported observations show that the theoretical increase in specific gravity which should accompany an increase in thorium is only a poorly developed trend.

Distinct cleavage is on the [100] plane, less distinct cleavage on the [010], and indistinct cleavage is rare on the [110], [101], and [011] planes. A strong parting occurs on the [001] plane and is thought to result from lamellar twinning (Frondel, 1958, p. 156). This parting, because of its perfection, has been questionably called cleavage (Dana, 1892). Parting is rarely present on the [$\bar{1}$11] (Palache and others, 1951, p. 693).

Monazite occurs most abundantly as subhedral to round grains, the roundest grains being found generally, but not exclusively, in detrital deposits. Small euhedral crystals from granitic rocks, schist, and gneiss are commonly tabular or wedge shaped and are accompanied by a fair to large proportion of subhedral to round grains. Monazite is rarely found in grains larger than 0.02 inch across, and particles of monazite weighing more than a few milligrams are rare in placers. Some granular masses and exceptional large single crystals have been discovered in uncommon geologic occurrences. In the southeastern United States a fragment of monazite weighing nearly 60 pounds was found near Mars Hill, North Carolina (Pratt, 1916, p. 38). The original crystal from which the fragment came is estimated to have weighed nearly 100 pounds; the fragment is regarded as the world's largest monazite crystal (Schaller, 1933, p. 436).

Monazite has high magnetic susceptibility, which, as Mertie (1953, p. 5) showed, is an inherent property deriving from the paramagnetism of the rare earths (Yost and others, 1947, p. 12–19) in the mineral. This property led Murata, Rose, and Carron (1953, p. 300) to infer that it would be possible to isolate monazite of specific composition through the use of a magnetic separator if a quantitative relationship could be found between the composition and the paramagnetism. In 1961 Richartz (1961, p. 54–56) reported the magnetic separation of monazite into six fractions of decreasing magnetic susceptibility from grains almost as magnetic as ilmenite to grains almost as nonmagnetic as zircon. A systematic variation in the abundance of the rare earths was observed in the fractions: the most magnetic grains contained the least lanthanum and cerium and the most neodymium, samarium, gadolinium, and yttrium.

Under ultraviolet radiation unaltered monazite neither fluoresces nor phosphoresces (Baskerville, 1903, p. 466), but it strongly absorbs violet, blue, and yellow radiation from an unfiltered mercury-vapor lamp and, as observed by the naked eye, assumes the green color of the unabsorbed radiation from the lamp (Murata and Bastron, 1956, p. 888). Monazite containing neodymium can be identified by a strong band in the yellow and a faint band in the green if the mineral is observed by hand spectroscope in reflected sunlight (Derby, 1889, p. 111; Kithil, 1915, p. 8; Mertie, 1949, p. 630).

Monazite undergoes no chemical or structural changes on heating to about 1,000°C in the atmosphere (Frondel, 1958, p. 157), but heating to 1,130°C sharpens the X-ray powder pattern and increases the specific gravity, index of refraction, and birefringence (Karkhanavala and Shankar, 1954, p. 71). The monazite structure was reported to show change to the xenotime structure at high temperature (Gliszczynski, 1939, p. 15–16), but such change was not observed by Karkhanavala and Shankar.

Liquid and gaseous inclusions are very rare, but they have been observed in monazite from localities in Brazil (Hintze, 1922, p. 354–355; Hussak and Reitinger, 1903, p. 551). Sillimanite, rutile, hematite, muscovite, biotite, quartz, epidote, apatite, magnetite, galena, and garnet have been found in monazite from several localities, but the mineral generally lacks inclusions.

OPTICAL PROPERTIES

Monazite is biaxial positive; relief is high and dispersion is strong. The greatest, intermediate, and least indices of refraction are 1.837–1.849, 1.788–1.801, and 1.787–1.800 (Winchell, 1933, p. 139). The optic angle ranges from 5° to 15°. In thin section or immersion oils, monazite is almost colorless, pale yellow, or pale yellowish brown; it lacks pleochroism. Distinct absorption is $Y > X = Z$. Like the other properties, the optical properties probably change with variation in the amount of thorium in monazite, but data are lacking (Frondel, 1958, p. 157).

CRYSTALLOGRAPHY

Monazite is monoclinic, in the prismatic crystal class, and is commonly tabular, wedge shaped, equant, or twinned (Frondel, 1958, p. 154–155). Summaries of crystal forms reported for the mineral have been given by Goldschmidt (1920, p. 51–57), Hintze (1922, p. 295–296), R. L. Parker (1937, p. 573), Palache, Berman, and Frondel (1951, p. 692), and Frondel (1958, p. 154). Interfacial angles of the same forms on crystals vary as the composition of the monazite varies. Comparison of crystals illustrated by Goldschmidt and geologic source of the monazite suggests that simple crystal form is common among monazite grains from vugs and low temperature veins and that complex forms tend to be common among monazite crystals from pegmatites. Monazite grains from plutonic gneisses and schists generally lack crystal form and are globular.

Summaries of the unit-cell dimensions and X-ray data of monazite have been given by Gliszczynski (1939, p. 2–14), Parrish (1939, p. 652), Pabst (1951,

p. 62), Ueda (1953, p. 230–244), Karkhanavala and Shankar, (1954, p. 69–70), and Carron, Naeser, Rose, and Hildebrand (1958, p. 263–265). The size of the unit cell varies with variation in the abundance of the different rare earths, but systematic variation of the cell dimension and abundance of thorium has not been demonstrated (Kato, 1958, p. 230). According to Ahrens (1955, p. 299), monazite is rarely if ever metamict, but Karkhanavala and Shankar (1954, p. 71) showed that X-ray data do not entirely support this contention and that thorium-rich monazite may attain a fairly high degree of metamictization.

COMPOSITION

Monazite is a thorium-bearing phosphate of the cerium earths. The cerium earths are the oxides of the metals lanthanum, cerium, praseodymium, neodymium, prometheum, samarium, and europium, which have atomic numbers that range from 57 for lanthanum to 63 for europium. The cerium earths include the elements of lower atomic number in the group of elements called the rare earths. Rare earths of higher atomic number, uncommon in monazite, comprise oxides of the metals gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, and yttrium.

Thorium, atomic number 90, is not a rare earth but is commonly associated with the rare earths in nature. It is classed with protactinium, uranium, and the transuranium elements in a radioactive group called the actinides (Rankama and Sahama, 1950, p. 570). Thorium is about four times as abundant as uranium in the earth's crust (Fleischer, 1953, p. 5). The first report identifying thorium in monazite was made by Kersten (1839, p. 186).

The abundance of thorium and rare earths in monazite, the ratio of thorium to the rare earths, and the ratio of cerium to lanthanum vary widely. Thorium may be absent, as in monazite from tin veins in Bolivia (Gordon, 1944, p. 330) and in monazite from carbonatite deposits in Africa (Mining World, 1954), or it may reach 31.5 percent, as it does in a rare variety of monazite from a pegmatite in India (Bowie and Horne, 1952, p. 2; 1953, p. 95). Murata and his associates have shown that systematic variations in the rare earths in monazite may be related to processes of fractional crystallization in nature (Murata and others, 1953, p. 292), but they have been unable to relate the content of thorium to that of any rare earth in monazite. The analyses given in this report make evident a correlation between the abundance of thorium in monazite and the geologic environment in which the monazite crystallized. Discussion of this correlation is reserved for the section on monazite in crystalline rocks. The cerium to lanthanum ratio is about 1:1 in nominal monazite [(Ce, La) PO_4] (Matveyeff, 1932, p. 228; Vainshtein and others, 1956, p. 161–162) and about 2.1:1 in monazite from the Southeastern United States (Murata and others, 1953, p. 294; Murata and others, 1957, p. 148).

Uranium is commonly present in monazite but rarely reaches amounts greater than 0.5 percent. Plutonium and neptunium in extremely small amounts have been detected in monazite from North Carolina and Brazil (Seaborg, 1958, p. 78–79) and are probably present in thorium- and uranium-bearing monazite from other localities:

	Percent	
	U	$(P^{239}/U) \times 10^{-12}$
North Carolina	1.64	3.6
Brazil	.24	8.3

Thorium, uranium, and samarium make monazite highly radioactive, a characteristic of the mineral first observed by Mme. Curie (1898, p. 1102). Some minor elements noted in its composition, like helium and lead, are at least partly of radiogenic origin.

Small amounts of the yttrium earths occur in monazite from many localities, but the ratio of the yttrium earths to cerium earths is always low.

Small amounts of calcium, magnesium, ferrous and ferric iron, aluminum, zirconium, manganese, beryllium, tin, titanium, and tantalum have been reported in various analyses of monazite. As much as several percent of silica may be present. These constituents appear in careful analyses of selected materials and are not just found in analyses of concentrates consisting of mixtures of monazite and other heavy minerals (Wylie, 1948).

To be marketable without penalties, monazite must have a total rare earths plus thorium oxide content of at least 65 percent (Lamb and others, 1953, p. 1355).

PRODUCTION AND USE

Monazite is the major source of thorium, and together with bastnaesite, a fluocarbonate of the cerium earths, is the principal source of the cerium group of rare earths.

An industrial need for thorium and the rare earths originated in 1883 when Carl Auer of Austria developed an illuminating gas mantle composed of the oxides of lanthanum and other metals. The composition of the mantles was gradually modified until, in 1891, a mixture consisting of 99 percent of ThO_2 and 1 percent of CeO_2 was accepted as best. Immediately after World War I and the general introduction of the tungsten-filament electric lamp, the declining demand caused a corresponding decrease in the production of monazite; however, new applications for thorium and the rare earths were found, and by 1935 world output of monazite had returned to its pre-War level. The United States, Brazil, India, and the Republic of South Africa have been the chief sources of monazite, but small amounts have come from many other countries. In the late 1950's uranothorianite [thorianite] produced in the Malagasy Republic and leach liquors from uranium ores produced at Blind River, Ontario, Canada, became important sources for thorium. Between 1880 and 1961 the world production of monazite, exclusive of the output in Europe and the U.S.S.R., was at least 271,000 short tons (table 1). The locations of the monazite-producing countries and the places where monazite has been found but not produced, exclusive of occurrences in Europe and the U.S.S.R., are shown on plates 1 and 2.

The uses of the rare earths have been discussed by many authors in recent years, and the reader is referred to their reports for details (see Lortie, 1943; Sanderson, L., 1943; West, C. A., 1944; Hammond, 1947; Johnstone, 1948; Mining Jour., 1954a; Lamb, 1955a, b; Baroch, 1957; Crawford, 1957b; Heinrich, 1958; Paone, 1958; Lewis, 1959; and Gibson and others, 1959). The following summary is drawn from a review by Lamb (1955b, p. 6–7). The rare-earth fluorides and oxides are used as cores of carbon electrodes to produce brilliant white light for projection of moving pictures and for high-speed photography. Lanthanum oxide is used to make optical glass of high index of refraction and low dispersion. Cerium metal serves as a reducing agent in some metallurgical processes and is a major component of pyrophoric alloys. Cerium oxide is an opacifier in porcelain and is used as an abrasive for polishing lenses and mirrors. Compounds of cerium are employed as oxidizing catalysts in organic preparations, as industrial driers, in various aspects of photography, and for the tanning of leather. Praseodymium and neodymium are used both to color glass and glazes and in mixtures to produce glass that absorbs ultraviolet light. A mixture of the rare earths in metallic form, called Misch metal, is used for pyrophoric alloys. Misch metal added to aluminum improves the stress-rupture properties of aluminum alloys at temperatures of 700°–800°F. Addition of Misch metal to magnesium increases its resistance to creep at temperatures between 400° and 600°F. Added to hot-dip aluminum baths, the rare earth alloys substitute for fluxes in producing smooth coatings on steel. The rare earths added to molten steel reduce the size of the grain in the steel, increase its resistance to low-temperature oxidation, and improve its workability. Rare-earth metals are excellent deoxidizing agents for copper and nickel. Other uses include chemicals for the waterproofing, weighting, and dyeing of cloth, and chemicals for printing inks and phosphors. Improved processes for the separation of the rare earths, separations formerly possible only through complex and costly fractional crystallization, should lead to their greater use by industry.

Thorium in nonenergy applications since World War II has been used chiefly for the manufacture of gas mantles and in magnesium alloys where the addition of 3 percent of Th to 96.3 percent of Mg and 0.7 percent of Zr improves resistance to creep (Crawford, 1957a, p. 2–3) and maintains strength at elevated temperatures. Small amounts of thorium are consumed as refractories and polishing compounds, as chemicals and medicines, and in electric apparatus.

Thorium-232, the common isotope of the element, is not a nuclear fuel but is a fertile material. By capture of a slow neutron, the thorium-232 becomes thorium-233, a negative-beta emitter which has a half-life of 23 minutes and disintegrates into protactinium-233. The protactinium-233 has a half-life of 27.4 days, is a negative-beta emitter, and disintegrates into uranium-233, an alpha emitter with a half-life of 1.63×10^5 years. Uranium-233 is fissionable by slow neutrons; hence, it is a possible fuel material for a sustained chain reaction (Glasstone, 1950, p. 400–401). The thorium-232 must be especially pure and free from the rare-earth metals. As little as 5 parts per million gadolinium in the thorium is enough to stop the reaction with slow neutrons (Franklin and Eigo, 1955, p. 80). Many aspects of the use of thorium in power reactors were discussed at the International Conference on the Peaceful Uses of Atomic Energy held in Geneva, Switzerland, in 1955. Reactors designed to supply electric power and breed uranium-233 from fertile thorium-232 were under construction by private industry and the U.S. Atomic Energy Commission in 1956 (Crawford, 1957a, p. 2–3).

Political considerations resulting from the use of thorium for energy purposes as indicated in this paragraph have led to restrictions, beginning in 1944, in the international traffic in monazite and to curtailment of publication of production, export, and import data on thorium-bearing ores and compounds. Thorium is a source material under the U.S. Congressional Atomic Energy Act of 1946; thus, producers of thorium compounds in the United States must be licensed by the U.S. Atomic Energy Commission, and statistics on the domestic output of thorium and thorium compounds are classified as security information. In 1944 Australia forbade shipments of monazite to markets out-

TABLE 1.—*World production of monazite, in short tons,*

[Data are from this report

Year	Africa						Asia	
	Malagasy Republic	Mozambique	Nigeria	Republic of South Africa	Republic of the Congo	United Arab Republic	Ceylon	Federation of Malaya [3]
1880	-	-	-	-	-	-	-	-
1886	-	-	-	-	-	-	-	-
1887	-	-	-	-	-	-	-	-
1888–92	-	-	-	-	-	-	-	-
1893	-	-	-	-	-	-	-	-
1894	-	-	-	-	-	-	-	-
1895	-	-	-	-	-	-	-	-
1896	-	-	-	-	-	-	-	-
1897	-	-	-	-	-	-	-	-
1898	-	-	-	-	-	-	-	-
1899	-	-	-	-	-	-	-	-
1900	-	-	-	-	-	-	-	-
1901	-	-	-	-	-	-	-	-
1902	-	-	-	-	-	-	-	-
1903	-	-	-	-	-	-	-	-
1904	-	-	-	-	-	-	-	-
1905	-	-	-	-	-	-	-	-
1906	-	-	-	-	-	-	-	-
1907	-	-	-	-	-	-	-	-
1908	-	-	-		-	-	-	-
1909	-	-	-		-	-	-	-
1910	-	-	-		-	-	-	-
1911	-	-	-		-	-	-	-
1912	-	-	-	[13] 3. 5	-	-	-	-
1913	-	-	-		-	-	-	-
1914	-	-	-		-	-	-	(9)
1915	-	-	-		-	-	-	-
1916	-	-	-		-	-	-	-
1917	-	-	-		-	-	-	-
1918	-	-	-	-	-	-	22. 4	-
1919	-	-	-	-	-	-	-	-
1920	-	-	-	-	-	-	80. 6	-
1921	-	-	-	-	-	-	84	-
1922	-	-	-	-	-	-	112	-
1923	1. 6	-	-	-	-	-	-	-
1924	[16] 1. 3	-	-	-	-	-	(17)	-
1925	-	-	-	-	-	-	-	-
1926	-	-	-	-	-	-	-	-
1927	-	-	-	-	-	-	[3] 168	-
1928	-	-	-	-	-	-	[3] 122	-
1929	-	-	-	-	-	-	[3] 93	-
1930	-	-	-	-	-	-	-	(9)
1931	-	-	-	-	-	-	-	-
1932	-	-	-	-	-	-	-	-
1933	-	-	-	-	-	-	-	(9)
1934	-	-	-	-	-	-	-	-
1935	-	-	-	-	-	-	-	-
1936	-	-	-	-	-	1. 1	-	-
1937	-	-	-	-	-	-	-	-
1938	-	-	-	-	-	-	-	-
1939	-	-	-	-	-	-	-	-
1940	-	-	-	-	-	-	-	-
1941	-	-	-	-	-	-	-	-
1942	-	-	-	-	-	-	-	-
1943	-	-	-	-	-	-	-	-

See footnotes at end of table.

1880–1961, exclusive of output in Europe and U.S.S.R.

unless otherwise noted]

Asia—Continued				Australia[1]	North America					South America[2]
India [4]	Korea	Thailand	Republic of Indonesia	Queensland and New South Wales	Florida	Idaho	North Carolina	South Carolina	United States [5]	Brazil [6]
----	----	----	----	----	----	----	0. 015	----	0. 015	----
----	----	----	----	----	----	----	(7)	----	(7)	----
----	----	----	----	----	----	----	12	----	12	[8] 15, 000
----	----	----	----	----	----	----	(7)	----	(7)	----
----	----	----	----	----	----	----	65	----	65	----
----	----	----	----	----	----	----	273	----	273	----
----	----	----	(9)		----	----	787	----	787	[10] 3, 307
----	----	----	5		----	----	15	----	15	192
----	----	----	(9)		----	----	22	----	22	249
----	----	----	----		----	----	125	----	125	2, 149
----	----	----	----		----	----	175	----	175	2, 932
----	----	----	----		----	----	454	----	454	1, 633
----	----	----	----		----	----	374	----	374	1, 811
----	----	----	----	(11)	----	----	401	----	401	1, 328
----	----	----	----		----	----	387	44	431	3, 636
----	----	----	----		----	----	343	29	372	5, 357
----	----	----	----		----	----	447	225	672	4, 891
----	----	----	----		----	[12] 2–3	349	74	423	4, 797
----	----	----	----		----	(12)	228	46	274	4, 891
----	----	----	----		----	(12)	155	56	211	5, 473
----	----	----	(9)		----	(12)	196	75	271	7, 121
----	----	----	----		----	(12)	42	8	50	5, 994
932	----	----	----	----	----	----	(12)	----	(12)	4, 064
1, 271	----	----	----	----	----	----	(12)	----	(12)	3, 746
1, 382	----	----	----	----	----	----	----	----	----	1, 584
1, 328	----	----	----	----	----	----	----	----	----	661
1, 241	----	----	----	----	----	----	18	----	18	484
1, 447	----	----	----	----	----	----	19	----	19	----
2, 173	----	----	----	----	11	----	39	----	50	1, 252
2, 371	----	----	----	----	----	----	----	----	----	551
2, 266	----	----	----	----	(14)	----	----	----	(15)	161
1, 838	----	----	----	----	----	----	----	----	----	1, 270
1, 411	----	----	----	----	----	----	----	----	----	366
140	----	----	----	----	----	----	----	----	----	127
276	----	----	----	----	----	----	----	----	----	----
697	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	1	----	----	----	----	22
72	----	----	----	----	----	----	----	----	----	221
314	----	----	----	----	----	----	----	----	----	224
115	----	----	----	----	----	----	----	----	----	112
202	----	----	----	----	----	----	----	----	----	99
16	----	----	----	----	----	----	----	----	----	17
101	----	----	----	----	----	----	----	----	----	----
732	----	----	----	----	----	----	----	----	----	331
156	----	----	----	----	----	----	----	----	----	449
1, 130	----	----	----	----	----	----	----	----	----	----
4, 277	----	----	----	----	----	----	----	----	----	----
2, 943	----	----	736	----	----	----	----	----	----	----
3, 451	----	----	408	----	----	----	----	----	----	460
5, 848	----	----	433	----	----	----	----	----	----	356
----	----	----	136	----	----	----	----	----	----	53
[18] 4, 561	----	----	----	----	----	----	----	----	----	198
[18] 3, 822	----	----	----	----	----	----	----	----	----	941
[18] 1, 430	----	----	----	----	----	----	----	----	----	1, 576
[18] 2, 099	----	----	----	(19)	----	----	----	----	----	1, 709

TABLE 1.—*World production of monazite, in short tons,*

[Data are from this report

Year	Africa					Asia		
	Malagasy Republic	Mozambique	Nigeria	Republic of South Africa	Republic of the Congo	United Arab Republic	Ceylon	Federation of Malaya [3]
1944	----------	----------	----------	----------	----------	----------	----------	[20] 220 (1944–45)
1945	----------	----------	----------	----------	----------	----------	----------	
1946	----------	----------	----------	----------	----------	----------	----------	
1947	----------	----------	----------	----------	----------	----------	----------	----------
1948	----------	----------	----------	(5)	----------	7	----------	----------
1949	----------	----------	----------	(5)	----------	3	----------	----------
1950	----------	----------	----------	(5)	----------	80	----------	----------
1951	----------	----------	(7)	(5)	41	1	----------	84
1952	----------	----------	4.5	[5] 300	15	7	16	63
1953	----------	----------	----------	[5] 5,000	12	7	56	208
1954	----------	----------	----------	[5] 9,000	4	9	51	391
1955	72	----------	----------	[5] 9,000	5	1	67	279
1956	168	----------	86	[5] 9,000	1	7	58	707
1957	331	0.5	104	[5] 9,314	----------	(7)	150	549
1958	----------	.1	64	[5] 8,112	----------	(7)	124	479
1959	----------	----------	15	[5] 2,402	----------	[27] 165	94	264
1960	471	1.0	13	(5)	----------	(7)	370	47
1961	503	.2	8	(5)	----------	(7)	239	780
Total	[23] 1,547.9	1.8	294.5	[4] 52,131.5	78	288.1	1,907	4,071

[1] Tasmania, 1900–05, small intermittent, unrecorded output; 1941, small amount in mixed concentrates, output unknown.
[2] Argentina, 1 ton produced in 1956.
[3] Exports.
[4] 1911–38, 1948 from Mertie (1953, p. 6); 1940–47 from Krishnan (1951, p. 298); 1951, 1958 from J. G. Parker, U.S. Bur. of Mines (written commun., 1962).
[5] 1948–61 from J. G. Parker, U.S. Bur. of Mines (written commun., 1962, 1963).
[6] 1895–1949 from Mertie (1953, p. 6); 1950–61 from J. G. Parker, U.S. Bur. Mines (written commun., 1962).
[7] Data on output not available.
[8] Surreptitious exports of concentrates, 1885–90 estimated by Leonardos (193,7a p. 3); possibly much less.
[9] Small but unspecified output.
[10] Exports from production in 1893–95.
[11] Small, intermittent, and unrecorded output in the late 1800's and early 1900's.
[12] Small production, not marketed.
[13] Output between 1900 and 1918 exact years unknown; part may be from Swaziland Protectorate.
[14] One producer, output unreleased, State unspecified.
[15] Figure withheld to avoid disclosing company's confidential data.

side the United Kingdom and the United States. The Atomic Energy Control Board of Canada regulates the development of thorium-bearing deposits and the disposal of ores. The Republic of South Africa has similar regulations. India restricted exports in 1946. At the beginning of 1951, Brazil ceased to issue export licenses but was, like India, considering offers of foreign firms to process monazite within the country (Leonardos, 1950; Mattos Netto, 1951; Lamb, 1955b, p. 3). Rare earths extracted from the monazite would be exported and the thorium retained in the country of origin. By the end of 1952 India had opened a state-owned plant at Alwaye, Travancore, for the processing of monazite concentrates, and the Government of Ceylon had constructed a pilot plant at Katurkurunda for placer monazite (Keiser, 1955, p. 1108). At Sâo Paulo and Victoria in Brazil, thorium and the rare earths were produced from placer monazite at two plants of the Industrias Quimieas Reunidas S.A., and export markets were sought for the rare earths (Strod, 1953, p. 123; Crawford, 1957a, p. 5). National controls and agreements have become a part of the international traffic in monazite.

The price of monazite has been affected by the political controls. It has increased from $50 to $60 per short ton prior to World War II to about $300 per short ton in 1955 for carload lots (f.o.b. West Chicago, Ill.). These prices are for material having a minimum of 55–60 percent of the rare earths plus thorium oxide (Franklin and Eigo, 1955, p. 78). In 1955 massive monazite having 55 percent total rare earths plus thorium oxide brought $0.13 per pound at ports in the United States, and the price per pound of monazite sand in the same year was $0.18 for 55 percent grade, $0.20 for 66 percent grade, and $0.22 for 68 percent grade. The prices are subject to negotiation, and quantity, quality, and the producer's refining costs are the chief considerations (Franklin and Eigo, 1955, p. 78). Prices per pound of rare-earth oxides in 1958 ranged from $1.85 to $1.90 for optical-grade cerium oxide to $850 to $900 for europium oxide (Lewis, 1959, p. 3). Pound lots of mixed rare-earth chemical compounds (sulfate, hydrate, carbonate, chloride, nitrate, acetate, fluoride, and oxalate) brought $0.25–$1.65; pound lots of thorium compounds (carbonate, chloride, fluoride, nitrate, and oxide) sold for $3–$8.50, and

1880–1961, exclusive of output in Europe and U.S.S.R.—Continued

unless otherwise noted]

Asia—Continued				Australia[1]			North America			South America[2]
India[4]	Korea	Thailand	Republic of Indonesia	Queensland and New South Wales	Florida	Idaho	North Carolina	South Carolina	United States[5]	Brazil[6]
										1,576
[18] 2,218	[21] 3,928	--------	--------	[22] 0.1	--------	--------	--------	--------	--------	3
[18] 1,724	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,135
[18] 66	([23])	--------	--------	--------	--------	}	{ --------	--------	}	{ 1,378
[18] 677	--------	--------	--------	--------	--------	} [24] 40	{ --------	--------	} [24] 40	{ 1,930
2,258	--------	--------	--------	[25] 942	--------	}	{ --------	--------	}	{ 2,205
([7])	--------	--------	--------	[25] 208	([15])	([15])	--------	--------	([15])	[3] 2,381
([7])	--------	--------	--------	[25] 175	([7])	([7])	--------	--------	[7] 767	([7])
530	--------	--------	--------	[25] 374	([7])	([7])	--------	--------	1,497	([7])
([7])	[26] 903	--------	--------	[25] 129	([7])	([7])	--------	--------	2,229	([7])
([7])	[26] 845	--------	314	[25] 283	([7])	([7])	([15])	--------	1,232	([7])
([7])	[26] 1,108	--------	11	[25] 199	([7])	([7])	--------	--------	1,971	2,976
([7])	[26] 560	--------	122	[25] 216	([15])	([15])	--------	([15])	1,219	([7])
([7])	[26] 203	18	([7])	[25] 268	([15])	([15])	--------	([15])	([15])	([7])
([7])	[26] 392	64	([7])	[25] 148	([15])	([15])	--------	([15])	[24] 2,006	([7])
4,122	[26] 355	1	([7])	[25] 474	([15])	([15])	--------	([15])	[24] 722	1,162
([7])	[26] 65	([7])	([7])	[25] 371	([15])	([24])	--------	--------	[24] 770	1,222
([7])	[26] 11	([7])	([7])	[25] 386	([15])	--------	--------	--------	([23])	1,153
([7])	[26] 854	([7])	111	[25] 1,739	([15])	--------	--------	--------	([23])	[27] 930
61,637	[29] 9,224	83	2,276	[30] 5,912	[31] 12	[31] 43	4,926	[32] 557	17,947	108,270

[16] Monazite and euxenite exports, first quarter only.
[17] Total output also said to be 700 short tons during 1918–29.
[18] Madras.
[19] Commercial production from beach sand, output not listed (Mining Jour., 1954a, p. 97).
[20] Additional 200 tons monazite-zircon concentrate shipped; tenor unknown.
[21] Monazite-zircon concentrate of unknown tenor; includes 1,598 short tons reported to contain 4–5 percent of monazite produced between 1942 and 1945 at the P'unggi placer in Kyŏngsang-pukto.
[22] Johnstone (1948, p. 615).
[23] Small, unrecorded output of monazite-fergusonite concentrate.
[24] Shipments.
[25] Total for high-grade concentrate, low-grade concentrate, and concentrate.
[26] Reported as concentrates containing 45–55 percent of RE_2O_3; also reported as 30 percent Ce, which may be high.
[27] Estimate, U.S. Bur. Mines.
[28] Items listed only.
[29] Includes 1,598 short tons of concentrate having 4–5 percent of monazite.
[30] Includes low-grade concentrate.
[31] Large output since 1949 not included.
[32] Large output 1955–58 not included.

thorium metal cost $12.50–$19.55 per pound in 1961 (Baker and Tucker, 1962, p. 4).

OCCURRENCE

Monazite is widely distributed throughout the world as a minor accessory mineral in intermediate- and high-rank metamorphic rocks derived from argillaceous sediments. It is less commonly present and less abundant as an accessory mineral in metamorphic rocks of like ranks formed from arenaceous sediments. Monazite is rarely present in metamorphosed calcareous or carbonaceous sedimentary rocks. It is especially common in pelitic schists, gneisses, and migmatites of the upper subfacies of the amphibolite facies and of the granulite facies. It may occur in magmatic rocks ranging in composition from diorite to muscovite granite and also in associated pegmatite, greisen, and vein quartz. In this group, accessory monazite is commonly observed in biotite quartz monzonite, two-mica granite, muscovite granite, and cassiterite-bearing granite. It has been more commonly reported in porphyritic granite than in aplite or felsite, but it has not been found as a primary constituent of silicic lava. Monazite is very rarely found in syenite but does occur locally in nepheline syenite and syenite pegmatite; it is abundant in carbonatite from many localities and in related alkalic volcanic rocks and dikes. It is not known to occur in mafic lavas, nor has it been observed in plutonic mafic rocks, but at a diamond locality in Brazil, monazite has been found in weathered mafic dikes and breccia of uncertain composition and origin. Monazite is found in a wide variety of veins, from simple quartz-chlorite veins and epithermal deposits, through mesothermal quartz veins and siliceous alteration zones, to hypothermal tungsten- and tin-bearing quartz veins and alteration zones associated with topaz and other minerals. Locally monazite occurs in vugs and druses.

As an accessory mineral, monazite rarely makes up more than a few hundredths of 1 percent of its host rock. Several extraordinary enrichments of monazite are known in plutonic terrane where thorium-rich monazite is concentated in veins formed by metamorphic differentiation. Other important concentrations in crystalline rocks include low-thorium oxide monazite in marble and carbonatite.

Pegmatite, although a source of monazite specimens for museums, is rarely a source of monazite ores and where monazite is present, it tends to be sparse. Monazite from pegmatite may locally contain exceptional amounts of thorium, and the monazite richest in thorium comes from pegmatite.

Erosion of crystalline rocks releases monazite for transport and accumulation in sedimentary rocks. Locally the processes of erosion and transportation may be varied and complicated, the detrital monazite traveling through several cycles of transport and deposition before being lodged in the deposits where it is presently found. Processes of glacial and wind erosion and transport are known to have released, moved, and concentrated monazite, but the most effective agents are those related to rock weathering, fluvial transport, and accumulation of weathered material on beaches. Rock weathering is especially effective in warm humid regions where chemical weathering exceeds the rate of erosion and thick mantles of thoroughly weathered residuum accumulate. Chemical weathering reduces the variety of heavy minerals in the crystalline rocks and residuum until only the most inert ones remain to form eluvial deposits and to be washed into streams. In streams the heavy minerals are further winnowed and mechanically concentrated into fluviatile placers. Stream placers are not static deposits. A constant flow of monazite-bearing sediment moves downstream to interior basins or to the sea where the discharged sedimentary materials are further sorted. The tide, alongshore currents, waves, and wind continue to work and rework the monazite. These processes tend to concentrate it with other insoluble heavy minerals in beach and dune placers. Economically the most important monazite deposits are beach placers, which are the end product of several stages of concentration of thorium and the rare earths. These stages are metamorphism which develops the primary source; weathering; concentration in streams; concentration in littoral sediments; and reconcentration in beach placers.

Recent placers are generally in unconsolidated sediments. Fossil placers are preserved in lithified sediments of many ages, and accessory detrital monazite is found in sedimentary rocks, mainly sandstone, of all ages from Precambrian to Quaternary. Fossil placers are especially common in rocks of Precambrian, Cambrian, Cretaceous, and Tertiary age.

The review of the geographic and geologic occurrence of monazite, forming the main part of this text, shows that monazite has a restricted occurrence in crystalline and sedimentary rocks evidently resulting from geologic control. In crystalline rocks the presence, amount, and composition of monazite are affected by chemical and physical aspects of the geologic environment, but in sedimentary rocks these relations are subject to mechanical processes in the environment. Thus, general aspects of the occurrences of monazite can be related to geologic cycles in crystalline and sedimentary rocks. A semblance of control related to geologic age of occurrences is actually an expression of physical and chemical factors in the cycles in crystalline rocks. In the following review of the occurrences of monazite, the economically most important deposits, beach placers, appear near the end of the discussion because they are interpreted to be the end product of the geologic cycle of monazite.

CYCLES IN CRYSTALLINE ROCKS

Occurrences of accessory monazite in crystalline rocks can be related to one of two formative cycles here called the metamorphic cycle and the magmatic cycle. Occurrences seem to be more common in the metamorphic cycle than in the magmatic cycle. For both cycles the geologic factors that generally and pervasively control the abundance of monazite in the host rock and the amount of thorium in the monazite are the temperature and the pressure existing at the time monazite crystallizes. (See table 2.) In the metamorphic cycle these factors are shown by the grade of regional metamorphism, but in the magmatic cycle the temperature and the pressure must be inferred from a greater variety of evidence.

The role of temperature and pressure in the two cycles of monazite may be conveniently summarized by referring to the concept of three zones of rock formation determined by regional geologic environment. The epizone has the lowest pressure and temperature conditions, the katazone has the greatest pressure and temperature, and the mesozone is intermediate.

Monazite in the epizone is characteristically of hydrothermal origin in veins, vugs, druses, and disseminations associated with shallow late tectonic or post-tectonic masses of granitic rock. Granitic rocks of the epizone, except the cassiterite-bearing granites, rarely contain monazite, and where they do, monazite is sparse. Monazite is unreported in the effusive equivalents of the granitic rocks. Highly differentiated alkalic volcanic rocks of the epizone contain low-thorium oxide monazite. Monazite is rarely found in epizonal slate, phyllite, or schist. Monazite formed in the epizone tends to be lean in thorium; locally, however, monazite from epizonal granite may be moderately rich in thorium. At those places in the epizone where monazite occurs in both granite and metasedimentary rocks, the amount of thorium in monazite from granite tends to be 200–800 percent greater than the amount in monazite from metasedimentary rocks.

TABLE 2.—*Amount of thorium oxide in monazite related to the geologic environment of the monazite*

[Complete analyses are given in appropriate geographic parts of the report]

Source of monazite	Location	Number of analyses	ThO_2 in monazite (percent) Minimum	Maximum	Average
Metamorphosed pelitic and arenaceous sedimentary rocks					
Greenschist facies:					
Talc schist	Republic of the Congo (Léopoldville)	1			0.2
Sericite phyllite	Minas Gerais, Brazil	2	0.00	1.09	.54
Albite-epidote-amphibolite facies:					
Quartzite	Federation of Rhodesia and Nyasaland	1			3.07
Amphibolite facies:					
Middle and upper subfacies:					
Biotite gneiss	New Zealand	1			5.32
Mica schist and gneiss	Minas Gerais, Brazil	5	3.3	6.1	4.9
Upper subfacies (sillimanite-almandine subfacies):					
Sillimanite schist	New Zealand	1			5.47
	North Carolina, U.S.A	16	3.4	9.0	4.8
Biotite schist	North Carolina, U.S.A	31	2.1	6.9	4.8
Biotite gneiss	North Carolina, U.S.A	9	3.7	8.8	5.4
Muscovite schist	Pennsylvania, U.S.A	1			4.5
Sillimanite schist	Washington, U.S.A	2	3.92	4.06	3.99
Granulite facies:					
Gneiss	Malagasy Republic	4	8.6	10.0	9.4
	Ceylon	2	8.7	9.26	9.0
Feldspathic granulite in charnockite	Ceylon	1			9.81
Monazite-apatite metamorphic differentiation assemblage.	Malagasy Republic	5	5.28	12.37	8.43
Monazite-apatite metamorphic differentiation assemblage.	Republic of South Africa	1			8.01
Metamorphosed calcarous sedimentary rocks					
Greenschist facies:					
Micaceous dolomite, magnesite-rich schist	Republic of the Congo (Léopoldville)	1			0.2
Amphibolite facies:					
Middle and upper subfacies:					
Calcite-diopside skarn	Quebec, Canada	1			(1)
Metamorphosed limestone intruded by granite and calcite pegmatite.	Malagasy Republic	1			1.05
Migmatites					
Amphibolite facies:					
Kyanite-staurolite subfacies	Central African Republic	1			6
Sillimanite-almandine subfacies	Northwest Territories, Canada	1			4.8
	North Carolina, U.S.A	3	5.77	7.72	6.83
Upper subfacies(?)	Malagasy Republic	1			6.9
	Sierra Leone	2	10.0	12.6	11.3
	India	1			10.7
Metamorphosed pelitic and arenaceous sedimentary rocks and migmatites intruded by granitic rocks					
Amphibolite facies:					
Lower middle subfacies:					
Mica schist, mica gneiss, granite	Georgia, U.S.A	1			4
Staurolite-kyanite subfacies:					
Staurolite schist, gneiss, granite	Taiwan	6	3.20	6.79	5.24
	Georgia, U.S.A	1			4.42
Staurolite schist, kyanite schist, mica schist, gneiss, granite, pegmatite.	North Carolina, U.S.A	10	3.30	7.28	5.1
Middle subfacies(?):					
Schist, migmatite, granite	Ghana	1			6.5
	Mozambique	1			5
Mica schist, injection gneiss, granite	Korea	1			6.9

See footnotes at end of table.

TABLE 2.—*Amount of thorium oxide in monazite related to the geologic environment of the monazite*—Continued

Source of monazite	Location	Number of analyses	ThO_2 in monazite (percent)		
			Minimum	Maximum	Average
Metamorphosed pelitic and arenaceous sedimentary rocks and migmatites intruded by granitic rocks—Continued					
Amphibolite facies—Con.					
Middle and upper subfacies(?):					
Schist, granite	Central African Republic	1			7
	Federation of Rhodesia and Nyasaland	1			7.1
Schist, granite gneiss, granite	Korea	1			5.5
	Brazil	5	5.0	6.49	5.8
Upper subfacies(?):					
Schist, gneiss, granite	Nigeria	6	2.30	8.00	5.03
	Queensland and New South Wales, Australia.	8	6.3	7.4	7.1
Garnetiferous gneiss, pegmatite	Rio de Janeiro, Brazil	2	7.2	7.5	7.3
Sillimanite-almandine subfacies:					
Garnet-sillimanite gneiss, two-mica granite	Malagasy Republic	1			4.1
Garnetiferous sillimanite schist, biotite gneiss, quartz monzonite.	North Carolina, U.S.A	36	3	7.28	5.5
Upper subfacies and granulite facies:					
Migmatite, gneiss, granite	Malagasy Republic	18	5.28	9.44	7.08
Gneiss, granulite, granite, pegmatite	Ceylon	1			10.75
Gneiss, schist, granite	India	33	5.0	11.0	8.6
Granulite facies:					
Granulite, granite	Ceylon	1			14.31
Igneous rocks					
Diorite and granodiorite:					
Diorite intrusive into slate	Victoria, Australia	1			6.6
Granodiorite	Mexico	1			±4
Granodiorite, postkinematic(?) in upper amphibolite facies gneiss.	Washington, U.S.A	1			2.74
Unclassified granitic rocks	Victoria, Australia	1			5.20
	Nova Scotia, Canada	3	2.9	8.6	5.3
	California, U.S.A	3	3.49	4.4	3.9
	Montana, U.S.A	2	4.1	6	5
	Virginia, U.S.A	1			6.8
	Bahia, Brazil	2	3.76	10.05	6.90
	Rio Grande do Norte, Brazil	1			8.1
	São Paulo, Brazil	1			1.99
Granitic rocks ranked by metamorphic facies of wallrocks:					
Greenschist facies(?):					
Postkinematic granite	Uganda Protectorate	1			.47
Epidote-albite-amphibolite facies(?):					
Microgranite	Sarawak	1			6.8
Lower and middle subfacies of amphibolite facies:					
Granite	Idaho, U.S.A	34	2.2	6.24	4
Staurolite-kyanite subfacies of amphibolite facies:					
Granite	North Carolina, U.S.A	1			5.19
Synkinematic quartz monzonite	North Carolina, U.S.A	2	4.21	4.64	4.42
Postkinematic quartz monzonite	North Carolina, U.S.A	3	5.6	6.9	6.4
Middle and upper subfacies of amphibolite facies:					
Granite	Korea	10	4.6	7.08	5.9
Granite, pegmatite	Korea	2	5.81	6.6	6.2
Granite, pegmatite, schist, gneiss	Bahia, Brazil	14	3.5	9.4	6.1
	Espírito Santo, Brazil	15	5.2	7.09	6.1
	Rio de Janeiro, Brazil	1			5.87
	Uruguay	1			4.1
Silliamanite-almandine subfacies of amphibolite facies:					
Gneiss	New Hampshire, U.S.A	1			2.48
Quartz monzonite	New Hampshire, U.S.A	1			5.06
Granite	New Hampshire, U.S.A	1			3.25
Synkinematic quartz monzonite	North Carolina, U.S.A	21	4.3	8.8	6.1
Synkinematic quartz monzonite, gneiss, schist	North Carolina, U.S.A	36	4.47	7.84	5.94
	South Carolina, U.S.A	29	3.00	7.85	5.77
Upper subfacies of amphibolite facies:					
Granite	Korea	1			7.3
	New Jersey, U.S.A	1			13.66
Gneissic biotite granite	Minas Gerais, Brazil	1			6.7

See footnotes at end of table.

TABLE 2.—*Amount of thorium oxide in monazite related to the geologic environment of the monazite*—Continued

Source of monazite	Location	Number of analyses	ThO₂ in monazite (percent)		
			Minimum	Maximum	Average
Igneous rocks—Continued					
Granitic rocks ranked by metamorphic faces of wallrocks—Continued					
Upper subfacies of amphibolite facies to granulite facies:					
Granite	Malagasy Republic	1			7.8
Cassiterite- and (or) wolframite-bearing granitic rock:					
Granodiorite, granite	Tasmania, Australia	3	2	7.29	3
Granite	Republic of South Africa	2	3.48	3.51	3.5
Granite(?)	Burma	1			7
Granite	Federation of Malaya	14	.62	9.41	5.1
	Thailand	2	5.7	5.7	5.7
	Indonesia	4	.00	3.4	1.7
	New South Wales, Australia	17	.35	2.2	1.0
Cassiterite- and wolframite-bearing granite	New South Wales, Australia	(2)	(2)	(2)	4.11
Cassiterite granite, cassiterite pegmatite	New South Wales, Australia	1			6.18
Granite	Queensland, Australia	3	1.2	3.0	2.3
Granite in slate	Tasmania, Australia	2	2.5	3.0	2.7
Granite	Alaska, U.S.A	1			−4
Gneiss, granite, pegmatite	Minas Gerais, Brazil	10	5.37	10.80	7.7
Aplite:					
Aplite and granite	Federation of Rhodesia and Nyasaland	1			6.2
Aplite-pegmatite	Colorado, U.S.A	1			.94
Pegmatite ranked by metamorphic facies of wallrocks:					
Greenschist facies	India	2	2.25	3.91	3.08
Greenschist or albite-epidote-amphibolite facies.	India	1			18.75
	South Australia	2	10.7	19.4	15.0
	Manitoba, Canada	2	14.42	15.63	15.02
Albite-epidote-amphibolite facies or lower subfacies of amphibolite facies.	Federation of Malaya	1			6
	Japan	1			5.53
Staurolite-kyanite subfacies of amphibolite facies.	South Australia	1			8.0
	Connecticut, U.S.A	5	8.0	10.8	8.7
	North Carolina, U.S.A	7	5.48	8.18	6.45
Middle subfacies of amphibolite facies(?)	Japan	1			6.49
	Ontario, Canada	1			7.32
	Quebec, Canada	4	3.38	4.25	3.64
	California, U.S.A	1			22.29
	Colorado, U.S.A	1			5.62
	Virginia, U.S.A	7	7.21	18.6	12.2
Middle and upper subfacies of amphibolite facies.	Korea	6	5.1	7.1	5.8
Upper subfacies of amphibolite facies	Malagasy Republic	1			15.38
	Mozambique	1			9.84
	India	9	4.0	31.50	10.2
	Korea	5	9.49	10.7	9.8
	Quebec, Canada	1			12.60
	New Mexico, U.S.A	13	6.70	12.0	9.1
	Bahia, Brazil	1			8.88
	Espírito Santo, Brazil	1			14
	Goiás, Brazil	1			9.8
	Minas Gerais, Brazil	17	6.0	15.3	8.8
	Rio Grande do Norte, Brazil	3	.41	8.4	3.8
	São Paulo, Brazil	3	10.93	11.6	11.3
Sillimanite-almandine subfacies of amphibolite facies.	North Carolina, U.S.A	50	3.8	11.2	6.1
	Minas Gerais, Brazil	3	5.3	10.17	7.3
Granulite facies	Malagasy Republic	1			1.83
	Ceylon	9	4.91	28.20	10.81
Other pegmatite	Federation of Rhodesia and Nyasaland	2	2.72	9.36	6.04
	Malagasy Republic	3	8.9	11.23	9.7
	Swaziland Protectorate	3	6.5	7.0	6.7
	Japan	7	6.0	11.73	9.4
	Korea	1			11.0
	New South Wales, Australia	1			1.63
	Queensland, Australia	2	5.73	6.22	5.97
	Western Australia	7	3.80	5.93	4.94
	Bolivia	1			10.1
	Minas Gerais, Brazil	15	5.68	17.0	8.4

See footnotes at end of table.

TABLE 2.—*Amount of thorium oxide in monazite related to the geologic environment of the monazite*—Continued

Source of monazite	Location	Number of analyses	ThO_2 in monazite (percent)		
			Minimum	Maximum	Average
Igneous rocks—Continued					
Akalic rocks:					
Nepheline syenite	Greenland	1			(1)
Carbonatite	Federation of Rhodesia and Nyasaland	3	.00	2.2	0.8
	Kenya	1			−1
	Republic of South Africa	2	2.07	2.40	2.23
	Arkansas, U.S.A.	1			.00
	California, U.S.A.	6	1	3.01	2.3
	Illinois, U.S.A.	1			4.4
Veins, alteration zones, and vugs					
Epithermal veins:					
Chlorite vein	Republic of the Congo (Léopoldville)	1			0.2
Mesothermal veins and alteration zones:					
Auriferous quartz vein	South Australia	1			.18
Opaline alteration zone in granite	Republic of South Africa	2	1.5	2.5	2.0
Hypothermal veins and alteration zones:					
Quartz-fluorite-molybdenite vein	Republic of South Africa	5	1.0	4.0	2.8
Wolframite-scheelite-quartz vein	Japan	1			4.51
Wolframite-quartz vein	Northern Territory, Australia	1			1
Cassiterite-wolframite-quartz vein	Queensland, Australia	4	(2)	(2)	4.1
Disseminated with tourmaline and apatite	South Australia	1			.16
Associated with talc, mica, and tremolite in shear zone between veins composed of ilmenite and hematite.	South Australia	1			8
Cassiterite-wolframite-topaz-quartz vein	Tasmania, Australia	1			3
Hydrothermal dissemination in marble	Idaho, U.S.A.	1			.85
Synkinematic quartz vein in sillimanite schist.	North Carolina, U.S.A.	1			6.1
Vugs:					
In quartz vein and spodumene pegmatite	North Carolina, U.S.A.	1			1.48
In cassiterite-quartz vein	Bolivia	1			.00
Druse in marble	Bahia, Brazil	1			.05

[1] Very low. [2] Range not given in source.

Monazite in the mesozone is typically of metamorphic or magmatic origin. It is a moderately common accessory mineral in pelitic schists and gneisses and in syntectonic and posttectonic granitic rocks, particularly quartz monzonite, two-mica granite, muscovite granite, cassiterite-bearing granite, and pegmatite. Monazite in the mesozone is more abundant in granitic rocks than in metasedimentary rocks, but both kinds of rock contain more monazite than their equivalents in the epizone. Monazite from rocks in the mesozone has more thorium than monazite from rocks in the epizone. The difference between mesozonal schist and mesozonal granitic rocks in tenor of thorium is not as great as the difference between these rocks in the epizone. Monazite from granitic rocks tends to contain from 50–200 percent more thorium than monazite from mesozonal schists and gneisses.

Monazite in the katazone tends to be about as abundant in metasedimentary rocks as in granitic rocks; moreover, it is much more common in both kinds of rock in the katazone than in the mesozone. Sillimanite schist and gneiss, granulite, silicic charnockite, and synkinematic quartz monzonite generally have copious accessory monazite. Furthermore, monazite in the katazone is especially rich in thorium. In only a few places is the amount of thorium in monazite from granitic rocks in the katazone more than 10–50 percent greater than the amount in monazite from metasedimentary rocks, and it is generally only 10–20 percent greater. Monazite formed in pegmatites associated with katazone or mesozone rocks locally contains more thorium than monazite from any other rocks.

METAMORPHIC CYCLE

As long ago as 1900 the metamorphic origin of monazite in paraschist was clearly described by Derby (1900b, p. 219–220), and in 1913 Hess (1913, p. 1028) recognized its formation in regionally metamorphosed rocks. The contrary opinion that particles of monazite in paraschists and paragneisses are relict detrital grains, however, is still generally held. Observations in the present work confirm the metamorphic origin of monazite in paraschists and paragneisses, and also show that monazite participates in a previously unrecognized metamorphic cycle. The chief features of this cycle as defined in clayey sedimentary rocks are as follows: Detrital monazite in the sediment is unstable in early stages of regional metamorphism so that at the onset of metamorphism it breaks down and shares its components with other minerals and detrital monazite as such disappears. As the grade of regional metamorphism increases, an environment is reached at which monazite is again stable, and metamorphic monazite begins to form at a few centers of crystallization, which multiply with increasing grade of metamorphism.

Many features of monazite in paraschists and paragneisses described in the main part of this report support the interpretation that this monazite is of metamorphic origin. These features are the direct relation between grade of metamorphism and amount of monazite in the rock; the inverse relation between amount of monazite in the rock and grain size of the original sediment; the lack of similarity between the range in grain size of particles of monazite in paraschists and paragneisses and the probable range in size in the original sedimentary rocks; correlation between physical properties of monazite and metamorphic grade of the host rock; inclusions in monazite identical with metamorphic minerals in the host rock; intergrowths between monazite and metamorphic minerals in the host rock; inverse relations between monazite, allanite, and other thorium-bearing minerals in metamorphic rocks; systematic variation in the amount of thorium in monazite related to grade of regional metamorphism of the host rock. A possible exception to the interpretation that monazite is metamorphic in origin is the occurrence of detrital monazite in quartzite.

The literature shows that there is a direct relation in paraschists and paragneisses between the amount of monazite and the metamorphic facies of the host rock. Accessory monazite is exceedingly rare in the greenschist facies, rare to sparse in the albite-epidote-amphibolite facies, sparse to common in the amphibolite facies, and common to abundant in the granulite facies. This relation can be seen in monazite-bearing areas throughout the world but is especially evident along the east coast of the Malagasy Republic, in Ceylon, India, Japan, the South Island of New Zealand, the Southeastern United States, and the Diamantina district of Brazil.

The literature shows that at uniform metamorphic facies an inverse relation exists between the amount of monazite in a metamorphic rock and the coarseness of grain in the sediment from which the metamorphic rock was formed. Greater amounts of monazite are found in paraschists and paragneisses formed from argillaceous sediments than in rocks formed from arenaceous sediments. This relation holds even for thinly interlayered units of metamorphosed sandstone and shale; monazite is chiefly in the biotite-rich or sillimanite-rich layers formed from the shaly component and is sparse or absent in quartzo-feldspathic layers formed from the more sandy components. That a greater amount of monazite is found in schist and gneiss of pelitic origin than in rocks of equivalent facies formed from sandstone and graywack is a reversal of the usual distribution of detrital heavy minerals in shale and sandstone. Coarse clastics ordinarily are richer in heavy minerals—including monazite—than fine-grained sedimentary rocks. Obviously some process other than initial sedimentary concentration is required to account for the inverse relation that exists after metamorphism. This inverse relation has received the most study in the metamorphic rocks of North and South Carolina.

A general lack of similarity has been noted in North and South Carolina, Ceylon, and the Malagasy Republic between the range in grain size of particles of monazite from paraschists and paragneisses and the probable range in grain size in the original sedimentary rocks. Poorly sorted monazite having a wide range in grain size is typical of schists and gneisses through the amphibolite facies, but at the granulite facies the range in grain size tends to become narrow. At low and intermediate metamorphic facies, a wide range of grain size in monazite from single samples of schist and gneiss can be interpreted to indicate a mode of formation independent of hydraulic transport and sedimentary deposition because the sedimentary process tends to perfect the sorting of heavy minerals (Trainer, 1930, p. 197). A reduction in range of grain size that correlates with increase in metamorphic grade is unlikely to reflect sedimentary sorting.

The specific gravity and the unit-cell size of monazite from metamorphic rocks seem to vary with metamorphic grade. Data are incomplete but suggest that the specific gravity of monazite increases and that unit-cell size decreases as the metamorphism of the host rock increases.

Inclusions in monazite at several localities are identical to metamorphic minerals in the host rock. Monazite also occurs intimately intergrown with metamorphic minerals in the host rock. These relations can be interpreted as resulting from the metamorphic growth of monazite. Noteworthy examples are intergrowths with sericite and chlorite in quartzite from Transvaal Province, Republic of South Africa; intergrowths with and inclusions of biotite and kyanite from North Carolina; intergrowths with kyanite from Minas Gerais, Brazil; and intergrowths with and inclusions of sillimanite from New Zealand and Connecticut.

A striking relation exists in metamorphic rocks—that is, as monazite becomes more abundant, allanite and (or) sphene become less abundant. At low metamorphic facies, allanite and sphene are common and monazite is sparse. As metamorphic facies increases to the staurolite-kyanite subfacies, the quantity of the three minerals increases. Above that subfacies, allanite and sphene decline in abundance and monazite increases. Monazite is common, but allanite and sphene are uncommon in the sillimanite-almandine subfacies. In the granulite facies, monazite is rarely accompanied by allanite or sphene; however, it may be associated with thorite and thorianite. The literature contains much evidence that allanite and sphene proxy for monazite as a host mineral for thorium at low grades of regional metamorphism, and it gives some evidence that thorite and, especially thorianite, proxy for monazite in rocks of highest facies. This relation between monazite and the minerals mentioned seems to be an expression of a sequential partition of thorium among mineral species in metamorphic rocks, beginning with thorium in chlorite, biotite, apatite, garnet, and allanite in the low grades, changing to allanite, sphene, and monazite in the middle grades, and to monazite, thorite, and thorianite at the highest grade. If, as sometimes supposed, the monazite consists of relict detrital grains, the arrangement here described is inexplicable.

The amount of thorium in monazite from metasedimentary rocks increases as the metamorphic facies increases. The results of 731 analyses of thorium in monazite are grouped in table 2 according to geologic environment and geographic distribution. Many of the analyses are of monazite from placers; thus, it has been necessary to use a geologic classification of sources that describes the crystalline rocks from which the placer monazite came. The first 230 analyses in the table are of monazite from metasedimentary rocks or from distributive provinces in which metasedimentary rocks are the dominant source. These analyses are followed by those of monazite from igneous rocks or from distributive provinces in which igneous rocks are dominant. The analyses disclose, despite their wide range and their various inconsistencies, that for metamorphic rocks the average amount of thorium oxide increases as follows:

	ThO_2	
Metamorphic grade of host rock for monazite	*Metasedimentary rocks*	*Metasedimentary rocks and migmatite*
Greenschist	0. 4	(1)
Albite-epidote-amphibolite	3	(1)
Amphibolite	4. 9	6. 1
Granulite	8. 9	9. 4

[1] Not represented among analyses.

No thesis of sedimentary deposition and preservation of relict detrital monazite through metamorphism can account for this worldwide direct relation between the amount of thorium in monazite and the metamorphic grade of the host rock.

Monazite in some quartzites locally may represent fossil placers, although in other quartzites it seems to be of metamorphic origin. Quartzite and conglomerate in the Mkushi district of the Central Province of the Federation of Rhodesia and Nyasaland contain concentrations of monazite that are probably fossil placers, but the amount of thorium in the monazite varies widely (O'Brien, 1958). The metamorphic grade of the monazite-bearing quartzites also varies widely. Vickers (1956a, p. 173–185) reported thorium-rich monazite in fossil placers that occur in Goodrich Quartzite in the Palmer area, Marquette County, Mich., but did not give any data on the regional metamorphism of the area. Quartzite and conglomerate exposed in the Sub Nigel mine, Transvaal Province, Republic of South Africa (Mendelssohn and Marland, 1933; Liebenberg, 1955, p. 147–148), apparently contain both detrital and metamorphic monazite, but the composition of the monazite is unknown. Fossil placers in quartzite, usually of low metamorphic grade, are reported from other localities, but such examples of relict detrital monazite are scarce compared to the extensive outcrops of monazite-bearing schists and gneisses which underlie hundreds of thousands of square miles of the earth's surface.

Monazite is rarely found in metasedimentary carbonate rock, and where found (Malagasy Republic, Federation of Malaya, Idaho, and Brazil), it seems to have been introduced hydrothermally or brought in by pegmatites. Monazite in metamorphosed carbonate rock is very lean in thorium. Although the calc-silicate rocks are rich in sphene in many localities, these rocks are not known to contain monazite, but this mineral may have been overlooked.

Monazite has been reported from carbonaceous sedimentary rocks which are highly metamorphosed but not from those which are slightly metamorphosed. Layers or veins of graphite in granitoid gneiss at two localities in Brazil were shown by Derby (1902) to contain as much as 7 percent of monazite. Derby stated that graphite-sericite schists in the same areas lack monazite. He suggested that this relation might be used to discriminate between graphite of possible igneous origin, which was thought to be associated with monazite, and graphite of sedimentary-metamorphic origin, which was thought to lack monazite. That metamorphic facies is the key to the presence or absence of monazite seems more probable. In North Carolina monazite is present in graphite-rich sillimanite schist of the amphibolite facies but is absent from graphite phyllite of the greenschist facies.

Retrogressive regional metamorphism might be expected to affect the abundance and composition of monazite in appropriate rocks. The small amount of evidence on this point in the literature is conflicting. Retrogressive metamorphism may have had no significant effect on monazite having about 8 percent of ThO_2 at Myponga Hill, South Australia (Rowley, 1956, p. 63). It is remotely possible, however, that, prior to retrogressive metamorphism, this monazite was much richer in thorium. Nearby unmetamorphosed rutile-bearing pegmatite contains monazite having 19.4 percent of ThO_2 (Wylie, 1950, p. 165).

Sericite phyllite said to have been formed by cataclastic deformation of muscovite granite at São João da Chapada, Brazil, contains fragments of monazite crystals which were interpreted by Moraes and Guimarães (1931, p. 524) to have been broken by the cataclasis. Interestingly, this monazite seems to contain only 1.09 percent of ThO_2 (Hussak and Reitinger, 1903, p. 560), a quantity that is considerably less than might be expected in monazite from muscovite granite but that is consistent with the amount to be expected in monazite from sericite phyllite.

Although retrogressive metamorphism might be expected to lead to the replacement of monazite by allanite, sphene, apatite, mica, or chlorite; no examples of this replacement are known.

Authigenic monazite in most metasedimentary rocks is derived from elements in other minerals and gels or precipitates in pelitic rocks. Original detrital monazite may supply only a small amount of the elements that form metamorphic monazite. Indeed, the general absence of monazite in many low-grade metamorphic rocks may be due primarily to a general sparseness of detrital monazite in sedimentary sequences, rather than to a loss of detrital monazite resulting from the instability of the mineral at the onset of regional metamorphism. The distribution of thorium in sedimentary rocks can be used as a guide for an interpretation of the source of authigenic monazite in metamorphic rocks.

A clear relation was shown by Jaffe and Hughes (1953) between the radioactivity and the grain size of sediment in samples from the bottom of the Chesapeake Bay. Silt and clay were found to be more radioactive than fine sand, and fine sand proved to be more radioactive than coarse sand. Breger (1955, p. 63) showed that in marine sediments the concentration of thorium does not increase with nearness to a land mass. Adams and Weaver (1958, p. 396–399, 412–413), Murray and Adams (1958, p. 267–268), Adams, Richardson, and Templeton (1958, p. 272), and Pliler and Adams (1959a) reported that thorium is more abundant in offshore shales than in nearshore sands and beach sediments. The data on the abundance of thorium in shales was summarized by Adams and Weaver (1958, p. 402), who reported a mean of 12±1 ppm Th in the average shale:

	Mean Th (*ppm*)
Gray-green shale, America (avg of 52 analyses)	13.1
Shales, Russian platform, U.S.S.R. (4795 analyses)	11
Bentonites, North America (avg of 69 analyses)	24
Average shale (estimate)	12±1

Thorium in shale and thoroughly weathered crystalline rocks was found principally in fine-grained secondary minerals, probably hydrolyzates, or fixed in clays (Pliler and Adams, 1959a, b).

The data on thorium are much less complete for sandstone and sand than for shale. Graywacke was estimated by Adams and Weaver (1958, p. 413) to contain possibly as much thorium as the source rocks from which it was derived, or possibly as much as shale, but analyses were not given. Analyses of common sandstone and beach sand, and of sandstone and beach sand enriched in heavy minerals, presented by Murray and Adams (1958, p. 263), showed that common sand contains from ½₀ to ⅓ as much thorium as the average shale. Murray and Adams (1958, p. 268) stated that the average amount of thorium in sandstone is difficult to determine because no information is available on placers in sandstone. In common sand very little of the thorium is associated with heavy detrital grains. Murray and Adams (1958, p. 263) gave 18 analyses of sand from the United States which showed a wide range in thorium content:

	Number of samples	*Average* Th (*ppm*)
Berea Sandstone	1	4
Ottawa, Berkshire, Roubidoux, and Saint Peter Sandstones	4	[1] 0.8
Gallup Sandstone	1	362
Sand from Placer County, Calif	1	24.6
Beach sand from Florida	1	159.8
Beach sand from Galveston Island, Tex	10	[2] 1.9

[1] Range, 0.67–0.93.
[2] Range, 1.5–2.2.

Five samples of sandstone analyzed by Adams and Weaver (1958, p. 399) had the following thorium content:

Source of sandstone	Th (*ppm*)
Zion Canyon, Utah	5.4
Similar, Calif.	4.5
Brownwood, Tex.	[1] 14.4
Cantuar, Alberta	1.0
Do	3.0

[1] Thorium by gamma-ray spectral analysis; other samples by alpha activity-fluorometric uranium method.

Probably the average sandstone has between 2 and 24 ppm of Th, the average possibly being 5.4 ppm (Rankama and Sahama, 1950, p. 573; Adams and Weaver, 1958, p. 402, 413; Murray and Adams, 1958, p. 265). Results of work by Jaffe and Hughes (1953), Breger (1955, p. 63), and Murray and Adams (1958, p. 263) suggested that in ordinary sedimentary sequences the amount of thorium is less in sandstone than in shale.

The distribution of monazite in metamorphosed shale and sandstone in North Carolina was shown by Overstreet, Yates, and Griffitts (1963a, pl. 1) to resemble the distribution of thorium in unmetamorphosed shale and sandstone. The average amount of thorium in many samples of monazite from each type of metasedimentary rock was identical, but the amount of monazite in metamorphosed shale was twice the amount of monazite in metamorphosed sandstone. In both rock types the amount of thorium attributable to monazite was much less than the amount of thorium in average shale or sandstone.

The source of monazite in the average metasedimentary rock is, therefore, interpreted to be thorium, rare earths, and phosphorus dispersed among the clays, mica, and apatite in the unmetamorphosed sediments. During progressive regional metamorphism these components differentially pass from one mineral phase to another. In the early stages of metamorphism, chlorite, biotite, garnet, and other minerals are the principal hosts for the rare earths, thorium, and phosphorus. As the host minerals disappear and new mineral phases enter or the composition of the earlier formed minerals changes to accommodate higher temperature, pressure, and stress, the components are held by different mineral phases among which monazite becomes more common as the grade of metamorphism rises. As the grade of metamorphism increases, the amount of thorium in the crystallizing monazite also increases. It is not known if this increase in thorium only affects monazite crystals forming at a given stage in the metamorphic history of the rock, or if there is continuous reaction between early formed monazite and other thorium-bearing minerals in the host rock. Inasmuch as the amount of thorium in separate samples of monazite from the same metasedimentary rock tends to vary widely (Overstreet, Yates, Griffitts, 1963a, p. F14), the reaction of earlier formed monazite was probably slow and incomplete, and the rate of diffusion of thorium was probably low. Although the amount of thorium held in monazite formed at the upper subfacies of the amphibolite facies is only about one-tenth of the amount of thorium in the average unmetamorphosed shale or sandstone, adequate thorium is present in other components of the schists and gneisses to allow the greater nucleation of monazite and to supply the higher tenors in thorium in the monazite found in schists and gneisses of the granulite facies. A relatively high rate of nucleation and a relatively low rate of diffusion in granulite may cause the abundance of fine-grained monazite characteristic of gneiss in the granulite facies. At the highest grade of regional metamorphism, some thorium in the rocks crystallizes as thorite and thorianite. Metamorphic differentiation of the granulite facies even leads to the segregation of aggregates of monazite and apatite and of thorianite, which migrate into veins. Examples of such aggregates are known in the Malagasy Republic.

Monazite seems to have been introduced hydrothermally or by pegmatites into a few metamorphosed carbonate sedimentary rocks. In general, however, the sedimentary carbonates contain very little thorium (Breger, 1955, p. 66). According to Adams and Weaver (1958, p. 402, 404), the amount of thorium in limestone correlates reasonably well with the abundance of insoluble matter, particularly shaly material, in limestone:

Source of limestone	*Mean* Th (*ppm*)
North America:	
54 individual samples	1.7
25 aggregates comprising 516 samples	1.1
Russian platform:	
13 aggregates comprising 5,475 samples	2.4

Organic debris is associated with concentrations of detrital monazite in Recent placers which may be covered by peat, muck, and carbonized wood. Black shale was reported to contain from 1.6 to 28 ppm Th (Adams and Weaver, 1958, p. 396), and detrital monazite is known in sediments underlying coal in Australia. Original detrital materials are probably the source of monazite in graphitic schist and gneiss, but the source of monazite in graphite veins or layers is uncertain.

MAGMATIC CYCLE

The magmatic cycle is here taken to refer to occurrences of monazite in solidified mobile rock material. It includes monazite-bearing rocks formed by partial or complete anatexis of sediments in orogenic belts.

Also included are monazite-bearing veins and alteration zones related in origin to these rocks.

Differentiation under plutonic conditions yields granitic masses of batholithic dimension in which monazite is a minor accessory mineral, but large volumes of monazite-rich rocks are not formed. Differentiation locally produces monazite-rich veins in the mesozone and epizone. Extreme differentiation of alkalic rocks forms large concentrations of thorium-poor monazite in carbonatite. Fractionation during crystallization in the magmatic cycle produces thorium-rich monazite in pegmatites. Among rocks formed in the magmatic cycle, accessory monazite is most common in granitic rocks, particularly in plutonic synkinematic granites emplaced contemporaneously with folding and metamorphism of wallrocks; thus, of the 478 samples of monazite from occurrences in the magmatic cycle (table 2), none is from a mafic igneous rock, only 1 is from diorite, and 2 are from granodiorite, whereas 254 are from granite and 204 are from pegmatite.[1]

Plutonic mafic rocks and their extrusive equivalents are not known to contain monazite, but the mineral has been reported from weathered mafic dikes and igneous breccia of uncertain composition intrusive into quartzite in the Diamantina district of Brazil (Derby, 1899, p. 348; 1900a, p. 209–213; Thompson, L. S., 1928, p. 709). The monazite-bearing mafic igneous rocks are described as sheared diabase, quartz-free greenish schist, and igneous breccia composed of blocks of quartzite in mafic material resembling the dikes. Composition of the monazite is unreported. Except for the greenish schist in the Diamantina district, metamorphosed equivalents of mafic igneous rocks are not known to contain monazite. Monazite occurs in granitic segregations in thorianite-bearing phlogopite pyroxenite of probable metasedimentary origin in the Malagasy Republic, but apparently it does not occur in the pyroxenite (Besairie, 1954, p. 107, 110; Roche and Marchal, 1956, p. 142–144; Behier, 1960, p. 50).

Rare occurrences of accessory monazite in diorite are recorded. At one locality in Australia, monazite-bearing diorite is intrusive into slate of the greenschist facies; this monazite contains 6.6 percent of ThO_2 (table 2). Granodiorite likewise is a minor source despite being widespread in orogenic belts. Only two analyses in table 2 are of monazite from granodiorite; the average amount of thorium oxide in these two analyses is 3.4 percent.

[1] The large number of analyses emphasizes the popularity of pegmatite for specimen crystals, but they greatly exaggerate the regional geologic role of pegmatite as a host rock for monazite. In many famous pegmatite districts for which an extensive geologic literature exists, it is common to find that for hundreds of dikes described, monazite is reported for only a few.

The dominant source rock for monazite in the magmatic cycle is granite, a term necessarily broadly used here to mean granular rocks composed of quartz, feldspar, and mica. Undoubtedly many occurrences in granodiorite, and possibly some in diorite, are lost in this usage, but nothing less comprehensive is suited to the literature, especially to old reports on mining in regions of weathered rocks. The main kinds of monazite-bearing rock included under granite are biotite quartz monzonite, quartz monzonite, two-mica granite, biotite granite, muscovite granite, cassiterite-bearing granite, and wolframite-bearing granite. Granites that formed during deformation in orogenic belts are far more likely to be monazite-bearing than postkinematic granites. Synorogenic granites that formed by regional metamorphism in the sillimanite-almandine subfacies or granulite facies are the main monazite-bearing rocks in the magmatic cycle. Synkinematic granites that crystallized under conditions of low-grade regional metamorphism, and postorogenic granites exclusive of the cassiterite-bearing granites, are lean in or devoid of monazite. Cassiterite-bearing granites and cassiterite-wolframite granites rarely lack monazite, and hornblende granites rarely contain monazite, regardless of spatial and temporal relations. Accessory monazite occurs sparingly in quartz porphyry, aplite, and felsite at a few scattered localities but monazite has not been observed as a primary mineral in silicic lava. Volcanic ash beds associated with fresh-water limestone in Victoria, Australia (Coulson, 1924, p. 169–174), contain minor accessory monazite, but the monazite is probably a detrital mineral introduced by stream action at the time the ash was deposited.

Good descriptions of monazite in granitic rocks are rare, because the mineral is not seen in most thin sections and in many its presence can be established only by the use of special methods infrequently employed in petrographic work. Heavy-mineral techniques disclose its presence where it makes up no more than 0.00001 percent of the rock (Overstreet, Yates, and Griffitts, 1963a, table 1). More extensive use of these techniques would doubtless reveal monazite in favorable terrane where it was previously unreported. Such use would tend to redress the disparity between the large number of occurrences reported in tropical, subtropical, and temperate regions, where the mineral is well known as a resistate in weathered rocks, and the very few occurrences attributed to subarctic and arctic regions, where weathering products were scoured from the rocks by glaciers.

An average of 5.1 percent of ThO_2 was found for the 254 samples of monazite from granitic rocks and for detrital monazite with distributive provinces mainly underlain by granite (table 2). Analyses of 178 of the samples can be ranked according to the probable metamorphic grade of the wallrocks in which the monazite-bearing granites are emplaced. Practically all the analyses are of monazite from granite in areas where the wallrocks are at the amphibolite facies. The spatial relation is thus established between monazite-bearing granites and metasedimentary rocks of the amphibolite facies, but the temporal relations are not shown by the table. The majority of the 178 analyses are probably of monazite from synorogenic granites. The amount of thorium in monazite from the granites increases as the metamorphic facies of the wallrock increases.

Thorium content in monazite from granite related to probable metamorphic facies of wallrock

	Number of analyses	ThO_2 (percent)		
		Minimum	Maximum	Average
Greenschist facies	1			0.47
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

A similar relation to metamorphic grade was observed for thorium in monazite from metasedimentary rocks.

The average amount of thorium in monazite from cassiterite-bearing granites is less than that in monazite from cassiterite-free granites, but this relation may be more apparent than real. Analyses of 62 samples of monazite from cassiterite- and (or) wolframite-bearing granites are given in table 2; these analyses show an average of 3.8 percent of ThO_2. None of these samples came from granite in granulite facies wallrocks, but 30 samples came from granite in unmetamorphosed sedimentary rocks and greenschist facies metasedimentary rocks. The amount of thorium in monazite from cassiterite-bearing granites progressively increases as metamorphism of the wallrock increases:

Metamorphic facies of wallrock	*Number of analyses*	ThO_2 *(percent)*
Greenschist	30	1.8
Albite-epidote-amphibolite	17	4.2
Amphibolite	15	6.9

In the cassiterite-bearing granites, monazite has more thorium than in the cassiterite-free granites for equal metamorphic facies of wallrocks. In cassiterite-bearing granites from the amphibolite facies, for which most data are available, an average of 15 analyses of monazite gives 6.9 percent of ThO_2, whereas an average of 175 analyses of monazite from cassiterite-free granites gives 5.6 percent of ThO_2. The low average tenor of thorium in monazite from the cassiterite-bearing granites, as reported in table 2, results from the fact that a large proportion of the analyses are of monazite from relatively shallow granite.

Monazite from 14 samples of unclassified granitic rocks (table 2) contained from 1.99 to 10.05 percent of ThO_2 and averaged 5.2 percent, an average which is nearly identical to that of all 254 samples of monazite from granite.

Monazite in granites generally has more thorium than monazite in the host rocks. As the environment of crystallization of both rocks becomes plutonic, the difference in amount of thorium decreases. Perhaps the amount of thorium converges where anatexis is complete (Winkler and Platen, 1958, p. 91; Walton and others, 1959).

Two samples of monazite from aplite (table 2) show a wide range and low average amount of thorium oxide: a range of 0.94–6.2 percent and an average of 3.5 percent. The fact that only two samples come from aplite, whereas 432 samples come from other granites and pegmatites, indicates that monazite is much less common in granitic differentiation products low in volatiles than in the more volatile fractions of the magma.

Analyses of thorium in 152 specimens of monazite from pegmatites are given in table 2 according to metamorphic facies of the wallrocks. Although the thorium oxide content of the monazite varies widely, the average is 8 percent; hence, the average monazite from pegmatite contains more thorium than the average monazite from granite. Table 2 shows that few monazite-bearing pegmatites occur in rocks of lower metamorphic facies than the middle subfacies of the amphibolite facies: only 9 out of 152 analyzed samples of monazite are from pegmatites in low-rank metamorphic terrane. No correlation was found between the amount of thorium in monazite from pegmatite and the metamorphic grade of the wallrock. This lack of correlation is interpreted to indicate that the abundance of thorium in monazite from pegmatites is related to the degree of fractionation of the pegmatite fluids in the local magmatic cycle. Fractionation of elements during crystallization of pegmatite has been shown by Murata, Dutra, Costa, and Branco (1958, p. 4, 9–12) to enrich the residual fluids in thorium and to systematically vary the composition of the monazite.

Analyses of 42 samples of monazite from other pegmatites in rocks the metamorphic grade of which is not known are given in table 2. The average amount is 7.7 percent of ThO_2, but the range in the amount is very wide.

Monazite-bearing varieties of alkalic rocks are rare, except for syenite pegmatites and carbonatites. Nepheline syenite in Greenland locally has minor accessory monazite which is reported to be very low in thorium (table 2). Monazite from the carbonatites is also low in thorium; the range shown in table 2 is from 0 to 4.4 percent of ThO_2, the average being 1.8 percent for 14 samples of monazite. The most thorium oxide-rich sample is from Illinois (No. 142, table 2). This monazite is associated with carbonate minerals and fluorite in a cryptovolcanic area. It contains large quantities of yttrium earths, and this composition has been interpreted as showing that it is relatively unfractionated and primitive (Trace, 1960, p. B64; Murata, and others, 1953, p. 296–297; Murata, and others, 1957, p. 148–150). Monazite-bearing volcanic alkalic rocks forming calderas and associated dikes and hydrothermally altered volcanic rocks are eroded to various depths in Africa (Smith, W. C., 1956, p. 189). The youngest and least eroded are in Uganda, and the oldest and most deeply eroded are in the Republic of South Africa. Monazite from carbonatite associated with those rocks tends to be more common and richer in thorium in the deeper parts of the complex. In the most deeply eroded carbonatite at Palabora in the Republic of South Africa, thorianite is present. Hence, the composition and abundance of monazite in the highly differentiated alkalic rocks is apparently controlled by pressure and temperature, and thorianite appears as a new mineral phase in the deepest part of the complex.

Monazite has been reported more commonly from epithermal and mesothermal veins and alteration zones than the number of analyzed samples given in table 2 indicates, but it is noticeably less common in these occurrences than in hypothermal veins. The 20 analyses given in table 2 show that the average amount of thorium in monazite increases from 0.2 percent in a sample from an epithermal vein to 3.4 percent in 16 samples from hypothermal veins and alteration zones.

Monazite from a vug in a hypothermal vein in Bolivia is devoid of thorium, resembling in this respect the low-thorium monazite in druses and vugs in pegmatites.

Most reported vein occurrences of monazite are in cassiterite and wolframite veins. Monazite is also known in quartz veins containing fluorite and molybdenite, in quartz veins containing hematite, in quartz veins containing carbonate and thorite, and in carbonate veins containing other thorium minerals and titanium- and niobium-bearing minerals. None of the vein deposits in the magmatic cycle has been a commercial source for monazite.

Allanite has long been known to weather very readily, and this characteristic accounts for its failure to appear in placers except in Arctic areas. Although its ready weathering invalidates studies based on grain counts of detrital minerals, or minerals in saprolite, as a guide to its distribution (Silver and Grunenfelder, 1957), allanite has been much more frequently observed in thin sections of unweathered rocks than has monazite. Accounts of the two minerals as seen in thin sections show that they are only associated in a restricted range of occurrence in the magmatic cycle, and allanite is present in many rocks which lack monazite. In general, accessory monazite is absent and accessory allanite is common in plutonic, hypabyssal, and extrusive mafic rocks and extrusive silicic rocks and their metamorphosed equivalents (Iddings and Cross, 1885, p. 111; Winchell, 1900, p. 206; Watson, 1917, p. 466; Smith and others, 1957, p. 367). Allanite is common in shallow granitic rocks where monazite is sparse, and evidence of the replacement of monazite by allanite in these rocks is common (Dietrich, 1961, p. 10). Similar replacements are quite common in granite pegmatite, but locally monazite may replace allanite. In alkalic rocks, examples of monazite mantled by allanite are known (Daly, 1903, p. 56). Allanite is an extremely rare mineral in plutonic silicic rocks. From these relations, allanite is interpreted to proxy for monazite as a host for the rare earths and thorium in the mafic rocks and hypabyssal or extrusive silicic rocks. Apatite, sphene, and the micas also enter this role, but the partition of thorium among them throughout the magmatic cycle has yet to be worked out in detail (Hurley and Fairbairn, 1957, p. 942; Vainshtein and others, 1956, p. 162–169).

CYCLE IN SEDIMENTARY ROCKS

The geologic cycle of monazite in sedimentary rocks begins with the freeing of mineral grains from rocks exposed at the earth's surface and ends with the onset of regional metamorphism of monazite-bearing sediments. The processes in operation are dominated by mechanical agents, which can be rather varied, except at the outset when chemical agents are active. As a result of these mechanical processes, the detrital monazite can occur as a sparse accessory mineral or can be concentrated locally in sedimentary rocks. Under unusual conditions such as transport from a small and highly concentrated original source of monazite, the mechanical processes can disperse instead of concentrate the monazite.

Monazite is released from the host rock by many forms of mechanical disintegration, but no mechanical process is as effective as chemical weathering. During weathering the soluble fraction of the host rock is removed and the insoluble residue collects as a mantle. Released grains of monazite concentrated near their site of origin constitute eluvial placers. Enrichment of monazite in the residuum may range from about 2 or 3 times to several hundred times its original abundance in the host rock, but generally the enrichment is about 10 or 20 times. In deeply weathered areas underlain by monazite-bearing residuum from metamorphic rocks of the amphibolite facies the residuum typically contains 0.5–2 pounds of monazite per cubic yard and rarely may contain 20 pounds of monazite. At many localities where stream placers on weathered rocks have been mined for detrital monazite, the eluvial placers have also been mined, but they have not been commercially important. The main importance of eluvial deposits is as a protore for stream placers. Where streams erode concentrations of monazite in weathered residuum, the stream placers tend to be richer in monazite and the concentrates contain a greater percentage of monazite than other heavy minerals; in areas where stream placers form over relatively unweathered bedrock, the reverse ratio exists. Hence, concentrates from streams in warm humid regions contain a smaller variety of heavy minerals and more monazite than concentrates from streams in more temperate regions. Most of the monazite placers of the world are in the tropical and subtropical regions.

Monazite is not completely resistant to weathering. Analyses of monazite from Brazil show that it alters to a dull earthy product through removal of thorium and other components. Under extreme conditions of weathering, monazite also has been found to leach preferentially along some crystal faces and to deposit as authigenic overgrowths on other crystal faces or around other monazite grains (Derby, 1898, p. 190). Loss of monazite from weathering or intrastratal solution in sedimentary rocks, however, is not as great as is indicated by the mineral-persistence data of Pettijohn (1949, p. 486–487), and detrital monazite is known, even in abundance, in ancient Precambrian sedimentary rocks. In areas of profound chemical weathering, monazite is more resistant to solution than hornblende, epidote, garnet, magnetite, and apatite, all of which are indicated by Pettijohn to be more persistent than monazite. Doubtless the vastly greater initial abundance of these minerals over that of monazite gives them an appearance of stability and monazite an appearance of instability.

During fluviatile transport, detrital monazite lags behind detrital quartz, feldspar, and other common minerals and is concentrated with such resistant minerals as ilmenite, rutile, zircon, and sillimanite. Monazite and other heavy minerals tend to settle to the bed of the stream where they are concentrated with the coarser fraction. In deeply weathered areas, most of the stream load is fine sand, silt, and clay; therefore, the tendency of monazite to settle into thin veneers of coarse clastics results in low tenors among fine-grained sediments. These low-tenor silt and clay deposits generally cover the high-tenor gravels. In the valleys of streams in the Southeastern United States, fluviatile clay contains about 0.1–0.3 pound of monazite per cubic yard, silt contains about 0.7–1.3 pounds of monazite per cubic yard, and gravel has 1.3–2.4 pounds of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710–711). Local concentrations in gravel at the heads of small streams may reach as much as 85 pounds of monazite per cubic yard (Mertie, 1953, p. 10). Throughout the world, like tenors have been noted for placers formed under similar geologic conditions. Only under specially favorable economic conditions can such deposits be mined for monazite alone. Stream placers have, however, been the source of commercial monazite (table 1) in the Malagasy Republic, Republic of the Congo (Léopoldville), Republic of South Africa, Federation of Malaya, Korea, Republic of Indonesia, Idaho, North Carolina, and South Carolina. Only those fluviatile deposts where monazite is accompanied by other valuable ores, such as cassiterite in Malaya or gold in Korea, seem profitable for sustained production.

Where monazite-bearing streams empty into lakes or oceans, deposits of heavy minerals tend to form at the mouth of the stream and along downdrift shores. Deltaic placers, particularly where further mechanical concentration has been effected by wind, such as occurs at the mouths of the Nile, have been mined for multiple products. Coastal deposits of great diversity are formed by the constant sorting action of currents, waves, tides, storms, and wind. Present beach deposits are likely to be thin and transient, though locally they may be of very high tenor. After storms some beaches may have surface layers containing as much as 90 percent of monazite. Fluctuations of the level of the strand result in the preservation of monazite placers in raised beaches, terraces, lagoonal deposits, or dunes. Fossil monazite placers may also be preserved on the presently submerged parts of the coast or on the continental shelves (Trumbull and others, 1958, p. 52–58). Beach, terrace, lagoonal, and dune deposits are the main source of commercial monazite. The exploitation of these placers in Brazil and India has provided most of the monazite in world commerce (table 1).

The richest coastal deposits occur where weathered crystalline rocks of the hinterland are separated from the ocean by a belt of coastal-plain sedimentary rocks, many of Cretaceous or Tertiary age. Prior sedimentary concentration in the coastal plain deposits forms a protore from which present beach sands are reworked. Belts of monazite-bearing coastal sedimentary formations back up the beach placers in India, the Southeastern United States, and Brazil. Similar belts of monazite-bearing sedimentary rocks are present along the coast of Africa, but they have not been as widely explored as those have in the Americas and India.

In some coastal areas the source of monazite in extensive placers is not known. Along the coast of Queensland and New South Wales, an extremely long and complex geomorphic history is indicated for the detrital monazite because the composition of the monazite is unlike any in presently exposed source areas.

Some beach deposits, like those in New Zealand, have had a complex fluvial-glacial history in which alongshore migration of monazite has continued through several geomorphic cycles. At least one monazite occurrence on the coast of Antarctica seems to have been caused by the ice-rafting of detrital monazite from an area of monazite-bearing plutonic rocks to an area of monazite-free volcanic rocks.

Monazite in consolidated sedimentary rocks is for the most part a very minor accessory detrital mineral. Most samples of sedimentary rocks in which accessory detrital monazite has been reported are conglomerate and sandstone. Monazite is very rare in shale and is absent in limestone, except for one locality in Australia where fresh-water limestone contains detrital monazite.

Consolidated sedimentary rocks adjacent to seams of coal in Western Australia contain minor detrital monazite, but the data do not indicate whether it is present in coal. Inasmuch as monazite occurs in unconsolidated carbonaceous debris and in metamorphosed carbonaceous rocks, it probably is present also in coal.

Tillite in Australia is locally monazite bearing.

Authigenic monazite is unknown in unmetamorphosed sedimentary rocks, but it has been described as a product of the extreme weathering of quartzite in Brazil (Derby, 1898, p. 190).

Fossil monazite placers are reported from unmetamorphosed consolidated sedimentary rocks of Cambrian and Tertiary age in the Western United States at scattered localities between Canada and Mexico. These placers are composed of thorium-rich monazite presumably deposited by processes similar to those that form placers in the present-day sedimentary cycle. In these areas and in others that are outside of humid and weathered regions, such occurrences might contain commercial sources of monazite.

The amount of thorium in monazite from placers varies from place to place in the world and depends upon the kind of crystalline rocks that were the source of the detrital monazite. In general the more plutonic the source rock the more thorium the placer monazite contains. The role of the sedimentary cycle in the thorium content of detrital monazite is, therefore, one of mechanical blending (Mertie, 1958, p. 5). Mixing during transport characteristically leads to uniform mechanical blends of detrital monazite from diverse sources. As a result, the amount of thorium in samples of monazite from placers varies less than the amount of thorium does in samples of monazite from crystalline rocks. The larger the province from which placer monazite is drawn, the closer individual samples approach a mean, although there is ordinarily a great range in the amount of thorium in individual grains (Richartz, 1961, p. 54–56).

ECONOMIC RELATIONS OF THE CYCLES

At only a few localities can monazite be mined from deposits formed during the crystalline cycles; these deposits are all in metamorphic rocks. During the early part of the 20th century, a small output of monazite was maintained for several years from a monazite-rich zone in biotite gneiss exposed near Shelby, N.C. In the 1950's, large tonnages of monazite were successfully recovered from a monazite-apatite vein at Steenkampskraal, Republic of South Africa; the vein appears to be a product of metamorphic differentiation. Most of the monazite used in commerce has come from Quaternary placer deposits formed in the sedimentary cycle. Beach and dune placers have been the leading commercial source, but lagoonal, terrace, deltaic deposits, and fluvial placers have also been mined. As of 1962 the discovery of exploitable monazite deposits seem more likely among products of the sedimentary cycle, particularly fossil placers and beach deposits, than among products of the crystalline cycle.

AGE RELATIONS

Abundance of monazite.—More occurrences of monazite in crystalline rocks are reported in Precambrian terrane than in areas underlain by younger crystalline rocks. Apparently, geologic age is an indirect rather than a direct controlling factor. It is indirect because regions occupied by Precambrian rocks contain a greater proportion of high-grade metamorphic rocks and of plutonic igneous rocks than younger parts of the crust, and plutonic rocks are the preferred host rocks of monazite. Precambrian rocks that are not plutonic, or that are otherwise petrologically unfavorable as a host rock, are as lean in or devoid of monazite as similar but geologically younger rocks. Conversely, petrologically favorable host rocks of Paleozoic or younger age are as rich in accessory monazite as similar rocks of Precambrian age.

Thorium content.—The average amount of thorium oxide in monazite is shown by the 731 analyses in table 2 to be 6 percent. The amount in monazite of Precambrian age more commonly exceeds the average than the amount does in monazite of Paleozoic or younger age. The greater richness in thorium of Precambrian monazite seems to be a function of the prevalence of plutonic terrane in Precambrian areas instead of an inherent difference in composition directly related to age. Monazite of similar origin, regardless of age, has similar abundance of thorium. Owing to the great half-life of thorium, 1.389×10^{10} years (Rankama and Sahama, 1950, p. 570), the tenor in thorium of even very old monazite was originally not much greater than it is at present. Although it is not directly related to thorium content, geologic age can be used as an indirect guide to areas most likely to have thorium-rich monazite.

MONAZITE LOCALITIES

AFRICA

Monazite is distributed throughout Africa in a wide variety of geologic environments. Perhaps its commonest occurrence is as an accessory mineral in Precambrian gneisses, schists, and migmatites, but noteworthy concentrations of monazite have been found in isolated quartz-apatite veins in the Republic of South Africa and in carbonatite bodies in Northern Rhodesia, Nyasaland, and Kenya. Monazite from the quartz-apatite veins is the major African commercial source for thorium; monazite from the carbonatites is strikingly lacking in thorium and is not an ore for that metal. Other thorium-bearing minerals in the African carbonatites, particularly pyrochlore, have attracted commercial attention as ores of thorium, the cerium earths, and niobium. Placers, especially beach placers, have been but little exploited for monazite despite the favorable environment. Placer mining should develop on a far larger scale than is suggested by the intermittent operations of the 1950's in the Nile Delta, Republic of the Congo (Léopoldville), Malagasy Republic, and Nigeria.

ALGERIA

The massif of homogeneous subporphyritic to porphyritic very coarse grained biotite granite of probable Precambrian age at In Tounine, Algeria, locally contains abundant accessory monazite (Illy and Launey, 1955, p. 112, 123). The massif is shaped like an ellipse, 12.5 miles long and 7.5 miles across, its major axis trending N. 27° W. athwart the foliation of migmatites. In age the granite was said to compare with the younger granites of Nigeria. Monazite is common in the western and northwestern part of the massif where it is associated with zircon and pink garnet.

Concentrates from small alluvial placers in the western part of the In Tounine massif contain abundant monazite, ilmenite, wolframite, and cassiterite, and less abundant topaz, some zircon, and sparse scheelite, fluorite, garnet, and epidote (Illy and Launey, 1955, p. 125–126).

CENTRAL AFRICAN REPUBLIC

Monazite was found as early as 1914 in the Central African Republic in diamond-bearing concentrates panned from alluvium in the Cheniandaka River, a tributary of the Ngrissi River (Brustier, 1934, p. 435). Accompanying minerals are rutile, zircon, tourmaline, kyanite, and garnet. The Cheniandaka crosses the contact between muscovite granite and an interlayered sequence of quartz-muscovite schist, graphite schist, micaceous quartzite, and graphitic quartzite. Accessory minerals in the schists are zircon, tourmaline, garnet, rutile, kyanite, and very fine grained lemon-yellow monazite. The monazite contains about 6 percent ThO_2. Although diamonds were not found in concentrates from the schist, Brustier surmised that diamonds formed from high-temperature contact metamorphism of the graphitic schist where the schist was intruded by the granite. Monazite was not found in the granite.

Monazite sand said to have 7 percent of ThO_2 was reported to occur at Jakundu (Marble, 1949b, p. 90).

Monazite-bearing pegmatites occur in migmatite to the south of Ippy in the Central African Republic (Bessoles, 1955, p. 22). Enclosed in the migmatites are layers of quartzite and mica schist, and associated with these rocks are two-mica gneiss, hornblende-biotite gneiss, amphibolite, and biotite-muscovite granite. The rocks are rich in microcline. Doubtless, monazite occurs in rocks other than the pegmatites.

ETHIOPIA

Monazite occurs in the alluvium of the Dacatà River at Errer in Ethiopia (Usoni, 1952, p. 70, pl. 5). It is also present at Quoscerscer about 12 miles east of Harrar.

FEDERATION OF RHODESIA AND NYASALAND

CRYSTALLINE ROCKS

Monazite was discovered in 1949 in concentrates from Changwena Stream which heads in the Irumi Hills in the Mkushi district of the Central Province of the Federation of Rhodesia and Nyasaland (O'Brien, 1958, p. 26; Cahen and others, 1953, p. 52; Colonial Geology and Mineral Resources, 1954, p. 291). Here the Irumi Hills are underlain by Muva quartzite and form part of the divide along the border with the Republic of the Congo (Léopoldville). The concentrates contain only 3–4 percent of monazite, and the tenor of the sediments in the valley of the Changwena is too low to support any form of placer mining.

The locality has, however, considerable interest as a place where the geologic cycle of monazite, particularly the relation of the abundance of thorium oxide in the monazite to the grade of metamorphism of the host rock. The sources of the detrital monazite in Changwena Stream are fossil placers in quartzite and conglomerate of the Muva System. Interbedded with the quartzite are thin bands of pelitic sedimentary rocks variously metamorphosed from the lowest subfacies of the greenschist facies to the intermediate subfacies of the amphibolite facies. Intrusive rocks do not occur in the area. Several monazite-bearing fossil placers have been found in the quartzite and conglomerate. One of the largest and best exposed is a ledge as much as 18 inches thick and 0.25 mile long which crops out at the lip of the upstream cataract of Changwena Falls. Another well-exposed monazite-bearing fossil placer forms Mumpu mountain at the northeastern end of the Irumi Hills. Seven samples of the monazite-bearing rocks were taken by O'Brien (1958, p. 28) from four localities. The samples were crushed and panned. Monazite and zircon occurred as well-rounded grains, but the ilmenite and other heavy minerals were present in euhedral form or as fragments of euhedral grains. O'Brien interpreted the round grains of monazite and zircon to be relict detrital particles preserving water-worn forms and the other grains to be the recrystallized products of the metamorphism which affected the Muva quartzite and conglomerate.

Early reports on the composition of the monazite from Changwena Stream indicated that the monazite contained 9 percent of $eThO_2$ (O'Brien, 1958, p. 26). This estimate was supported by the following chemical analysis of alluvial monazite from the Irumi Hills made by the Chemical Research Laboratory, Teddington, England (Holmes, Arthur, 1954, p. 613):

	Percent
U_3O_8	0.10
ThO_2	9.29
Pb	.58

A sample of monazite from the Muva quartzite, however, was analyzed by the Department of Scientific and Industrial Research, Teddington, England, (O'Brien, 1958, p. 28) and was found to have the following thorium oxide content:

	Percent
U_3O_8	0.08
ThO_2	3.07
Pb	.19

O'Brien postulated that the original source of the detrital monazite in the fossil placers in the Muva quartzite might be granite and that the source could have been some hundreds of miles away. The source has not been found.

Although the amount of thorium oxide in the monazite from the quartzite is somewhat lower than that ordinarily associated with monazite from granite, such tenors are known from the upper parts of large batholiths, such as that in Idaho, U.S.A., and from the shallow tin-bearing granites of Indonesia. Erosion since Muva time might well have stripped away the parts of the granitic bodies that originally yielded monazite of lower thorium oxide content, and might have exposed rocks with accessory monazite having almost twice as much thorium oxide.

It is possible that the present low percentage of thorium oxide in the monazite from the quartzite may have resulted from reduction of an originally greater amount by the regional metamorphism that acted on the Muva System; this metamorphism may have caused the recrystallization of ilmenite and other associated heavy minerals. Abundances of thorium oxide of about 3 percent are very commonly associated with monazite from metamorphic rocks of the albite-epidote-amphibolite facies. If the original abundance of thorium oxide was more than 3 percent (the determination of about 9 percent of ThO_2 in monazite from streams in the Irumi Hills may be the tenor of the least altered monazite in the region) and if the composition of the monazite changed as the grade of metamorphism changed, then 3 percent of ThO_2 might be expected in monazite from Muva quartzite metamorphosed to the albite-epidote-amphibolite facies. Inasmuch as the quartzite has been affected by a wide range of metamorphic grades (O'Brien, 1958, p. 27), the monazite in it might be expected to exhibit a variation in its thorium oxide content, and the variation should relate to the metamorphic grade. It would be interesting to know which rocks contain monazite having 9 percent of ThO_2 and which contain monazite having 3 percent of ThO_2.

Original variation in the composition of the detrital monazite in the fossil placers is unlikely to have been very large, because the processes of erosion, transportation, and deposition are efficient blenders. Placer monazite is usually similar in bulk composition throughout the placer district, despite possible wide variation in the amount of thorium oxide in individual grains; therefore, it is reasonable to assume that changes in the composition of the monazite in different parts of an extensive fossil placer are produced by conditions operating on the mineral after the placer was formed.

Absence of intrusive rocks in the Irumi Hills area further adds to the excellence of the area as a place in which to study the behavior of monazite during metamorphism.

Peculiar green cryptocrystalline monazite forms minute spherulites in thin cracks in carbonate minerals or in silicified carbonatite in the volcanic plug that forms the prominent Nkumbwa Hill 15 miles east of Isoka (Reeve and Deans, 1954, p. 271–277). The carbonatite plug is composed of dolomite and either ankerite or siderite. The carbonatite contains apatite and other phosphate minerals including monazite and accessory pyrochlore and sellaite. Carbonatite forming the summit of Nkumbwa is completely silicified. Around the base of the plug are sparse outcrops of biotite gneiss, hornblende gneiss, and granite. Monazite from Nkumbwa is practically nonradioactive; therefore, it contains virtually no thorium.

Four monazite-bearing carbonatite ring complexes lie along an east-southeast-trending arc in the valley of the Luangwa River near the mouth of the Rufunsa River in the Central Province (Bailey, 1958, p. 35–37). The most southerly of the carbonatite bodies forms the hill called Chasweta. From south to north the other three carbonatite complexes are known as Mwambuto Hills, Nachomba Hill, and Kaluwe. They lie in a downfaulted block of arenaceous sedimentary rocks.

Chasweta is the main vent of an eroded volcano having varied and complex lithologic and intrusive relations (Bailey, 1958, p. 38). Calcareous pyroclastic rocks fill the main vent, and a variety of carbonate dikes, crushed potassium-feldspar rock, fine to coarse agglomerate containing variable amounts of sandstone inclusions, and silicified and limonitized carbonatite are present. Concentric flow banding is locally well formed in the carbonatite core of the vent. The chief accessory minerals are barite, iron oxides, pyrochlore, very fine grained monazite, and rutile.

Mwambuto Hills are 7 miles west-northwest of Chasweta (Bailey, 1958, p. 39). They form an isolated ring 3 miles across that encloses a circular depression 1 mile in diameter. The structural feature has been recognized as a volcanic neck. Nachomba Hill is 9 miles northwest of Mwambuto Hills. It is a circular peak 0.5 mile in diameter consisting of silicified, limonitized, and phosphatized carbonatite that rises in the northern part of a circular depression about 3 miles in diameter. Kaluwe is a hill of carbonatite 5 miles north of Nachomba Hill. Little work has been done there, and its geology is not well known.

Monazite is probably present in all four carbonatite bodies, but was only mentioned by Bailey in the description of Chasweta. Pyrochlore is present in each of the carbonatite bodies. The abundance of thorium in the monazite was not indicated.

Monazite is disseminated in quartz-feldspar granulite near Dedza, in garnetiferous biotite-quartz gneiss near Masamba village, and in epidotized bands of gneiss near Kasupe north of Zomba (McNaughton, 1958a, p. 26; 1959). The Zomba locality has been known since 1911 as the source of fluvial concentrates having about 15 percent of monazite (Dunstan, W. R., 1911, p. 17), but minable deposits of monazite have not been found. Aplite dikes on Lungu Hills contain monazite and are regarded as one of the possible sources of the detrital monazite found in placers on the shore of Monkey Bay, Lake Nyasa (McNaughton, 1958a, p. 27). Monazite-bearing soil of unspecified origin occurs 3 miles west of Balaka (McNaughton, 1959).

Low-thorium oxide monazite is an accessory mineral in carbonatite rocks of volcanic origin in the Chilwa series in Nyasaland (Thomson, 1952a; Mining World, 1954; Lombard, 1955, p. 313; Cooper, W. G. G., 1957; p. 21). The most noteworthy occurrence of monazite is in the carbonatite complex at Kangakande Hill (Kangankunde Hill, Kangkangunde Hill) in the Senzani area of the Zomba district of Nyasaland (Garson, 1958a, p. 7–10; Smith, W. C., 1956, p. 195). At the Kangakande vent the Precambrian basement complex is fenitized and is separated from the central plug of the vent by contact breccia and feldspathized agglomerate. The agglomerate and fenite are carbonatized over an area about 2,100 feet long by 1,200 feet wide. During the first stage of the carbonatization, the rocks were soaked with strontianite, ankerite, and siderite, and along with these minerals were introduced small amounts of pyrochlore and barite. As carbonatization increased, monazite, florencite, synchysite, bastnaesite, pyrite, sphalerite, and galena were introduced. Monazite and the other rare-earth minerals commonly form spherulitic structures in the carbonatite.

Much of the inner northern part of the carbonatite complex, an area about 750 by 600 feet in size, contains 4–5 percent of green fine-grained monazite. An analysis by the Mineral Resources Division of the Federation of Rhodesia and Nyasaland disclosed that this monazite contained the following amount of thorium oxide (Garson, 1958a, p. 9):

	Percent
Ce_2O_3	32.5
La_2O_3 (group)	35.6
ThO_2	.4
P_2O_5	30.9
Insoluble in H_2SO_4	.4
Total	99.8

The amount of monazite in the carbonatite is throught by Garson to remain fairly constant with depth; thus, a reserve that has many millions of tons of ore containing 4–5 percent of monazite is available. Fine grinding is needed to separate the monazite from the other constituents; however, as late as 1958, methods for the final separation of the finely ground monazite from strontianite had not been perfected.

An iron-stained feldspathic dike containing several percent of disseminated fine-grained light-brown monazite and a few percent of intergrown bastnaesite and parisite is exposed 2.5 miles to the northwest of the northern part of Kangakande Hill (Garson, 1958b, p. 16). This monazite has 2.2 percent of ThO_2.

Thorium-poor monazite has also been found in the carbonatite bodies at Shirwa Island (Chilwa Island) and Tundulu Hill (Davidson, 1956b, p. 208).

Monazite is an accessory mineral in the cassiterite-bearing pegmatite dikes at the Jack tin claims north of Salisbury, Southern Rhodesia (Holmes, Arthur, 1954, p. 613; Colonial Geology and Mineral Resources, 1954, p. 291; Holmes and Cahen, 1955, p. 26; Ahrens, 1955, p. 295). The dikes also contain lithium-, beryllium-, and tantalum-bearing minerals. Monazite from these dikes contains 9.36 percent Th and 0.19 percent U (Holmes, Arthur, 1954, p. 613). It is also an accessory mineral in pegmatite dikes at the tin and tantalum field in the Bikita district (Barlow, 1934, p. 42; 1955, map; Cahen and others, 1953, p. 52; Holmes, Arthur, 1954, p. 613; Colonial Geology and Mineral Resources, 1954, p. 291; Holmes and Cahen, 1955, p. 26; Ahrens, 1955, p. 295). The principal monazite locality is about 25 miles northwest of Bikita. Monazite from a tantalite-bearing pegmatite at the Ebonite tantalum claims, about 4 miles southwest of the main Bikita tin field, contains 2.72 percent of ThO_2 and 0.087 percent of U_3O_8 (Holmes, Arthur, 1954, p. 613).

FLUVIAL DEPOSITS

Monazite has been said to be present in most rivers in Northern Rhodesia that drain from granitic terrane. Thirty-six concentrates panned by Davidson (1953, p. 75) from gold placers near the border with the Republic of the Congo (Léopoldville) contained from 3 to 10 percent of thorium oxide-rich monazite; however, in only a few places does the tenor of the fluvial sediments reach 2 pounds of monazite to the cubic yard, and no deposit suitable for dredging had been discovered by 1955 (Davidson, 1956b, p. 208).

Occurrences of detrital monazite in the streams in Nyasaland were widely noted as early as 1906 (Dunstan, W. R., 1908, p. 10–35), but none proved to be an economic deposit of the mineral. Since that time several of the occurrences of detrital monazite have been traced to their bedrock sources (Alexander, J. B., 1939, p. 20–21; Cooper W. G. G., 1957, p. 21).

Monazite-bearing concentrates were reported by W. R. Dunstan (1908, p. 15–35; 1909, p. 36–38; 1911, p. 9–17) at several localities.

Monazite-bearing streams in Nyasaland

[Sources: Dunstan (1908; 1909; 1911). Trace, less than 1 percent; present, between 1 and 2 percent]

Stream	Monazite (percent)
Ndeka River, Ncheu	0.4
Kungus River, tributary to the Livulezi River	.07
North and south branches of the Lisungwe River	Trace
Three localities on Nyankokola River	Trace
Chikukala River	1.5
Tributary to Ngena River near Tambani	Trace
Dwali River near Msen	Trace
Mwanza River near Myowe Hill	Trace
Nankande River	.5
Ngoma River	1.5
Nyamadzere River	Trace
Nyangundi River	Trace
Lifuluni River, tributary to the Ruo River	Trace
Nswadzi River	Trace
Zanseu stream near Lungudzi	Trace
Stream opposite Dowa Boma on the Lingadzi River	Trace
Makeye River	Present
Songwe River near Msikuora	Present
Stream below Milonde's village	Present
Kaseya River	Present

Monazite-bearing streams in Nyasaland—Continued

[Sources: Dunstan (1908; 1909; 1911). Trace, less than 1 percent; present, between 1 and 2 percent]

Stream	*Monazite (percent)*
Lufira River 2 miles up the gorge	Present
Lufira River near Mweniweyma	Present
Lufira River near Changoroma Hill	Present
Few miles from source of River Chungu	Present
Sere River near Sere village	Present
Ziwa stream near Muoma Hill	Present
Near Chemenyonga village and Muoma Hill	Present
Mwesia River at Mpata	Present
Vungwu River near Mwenemguwe	Present
Head of Fuliwa River	Present
Kaswenta stream near Majimpula village, south-central Nyika	Present
Katise stream near Mapangania village, south-central Nyika	10
Luviri River near Katemba village	Present
Michowo stream near Ngaloto village, northwestern Nyika	Present
Rumpi River near mouth	Present
North of Njowi village, Henga valley	Present
Nhuju stream, Henga valley	Present
Stream by Njowi village	Present
Lufiri River near Salimu village	3
Liwasi River northeast of Kulumani village	13
Chisita stream, tributary to Dwangwa River	4. 5
Dwangwa River near Litala village	4. 5
Dwangwa River near Kapyanga village	4
Dwangwa River near Tambala village	3
Small stream just below Zomba village on the Dwangwa River	15

Mostly the monazite is present in the concentrate in abundances of 1–5 percent. In a few places, it reaches 15 percent of the concentrate. Chief associated minerals are ilmenite, magnetite, garnet, hornblende, rutile, and zircon and less abundant epidote, sillimanite, tourmaline, and kyanite, and sporadic apatite, pyroxene, spinel, titanite, andalusite, and gold. Streams in the Tambani region mentioned by Dunstan were later reported to be the source of 39 monazite-bearing concentrates out of 40 concentrates examined (Davidson, 1956b, p. 208; 1959a, p. 179). Thorite, pyrochlore, and betafite were observed in 25 of the concentrates, and uranothorite was found in 11. According to Davidson (1956b, p. 208), the source of this assemblage of heavy detrital minerals is syenite and other crystalline rocks.

Detrital monazite of unknown origin from a stream at Namalundo Hill near Chiromo (Dixey, 1930, p. 11) in the southernmost part of Nyasaland was analyzed by Johnstone (1914, p. 57; Imp. Inst. [London], 1914a, p. 58) and found to have the following composition:

	Percent		*Percent*
Ce_2O_3	32. 52	SiO_2	1. 66
La_2O_3 (group)	26. 91	Al_2O_3	. 20
Y_2O_3 (group)	1. 51	Fe_2O_3	1. 10
ThO_2	7. 10	CaO	. 32
P_2O_5	28. 16	Loss on ignition	. 25

Concentrates from streams at 70 localities in areas underlain by crystalline rocks in the southern part of Nyasaland were reported by Dixey (1930, p. 11) to contain monazite. In order of relative abundance the minerals in the concentrates were ilmenite, magnetite, garnet, zircon, apatite, sphene, epidote, rutile, kyanite, sillimanite, spinel, tourmaline, staurolite, andalusite, and monazite. Alluvium from the Mwanza River was shown to be monazite-bearing, thereby confirming earlier identification by W. R. Dunstan (1908, p. 26). Monazite was found in alluvium of the Tangadzi River.

A few grains of monazite have been noted in a concentrate made from stream sediments in the Njakwa Gorge area of the Mzimba district, Nyasaland (Alexander, J. B., 1939, p. 20–21). Most of the concentrate consisted of magnetite, hematite, garnet, and zircon, and small amounts of epidote, hornblende, and pyroxene. In the Njakwa area the rocks are low-rank schists intruded by porphyritic orthoclase-hornblende-biotite granite.

Sparse monazite occurs with low-titanium oxide ilmenite near Port Herald in the alluvium of the Shire River, the outlet of the Lake Nyasa (Dixey, 1926, p. 210; 1930, p. 11; McNaughton, 1958a, p. 27). Only a small volume of alluvium was said to be present (Marble, 1949b, p. 91).

LACUSTRINE PLACERS

Monazite placers were discovered in the beaches at Monkey Bay on Lake Nyasa in 1955 (Mining World, 1957a; McNaughton, 1958a, p. 27). After this initial discovery, other lacustrine monazite placers were found toward the north end of Lake Nyasa and on the east shore of Lake Nyasa opposite Monkey Bay (McNaughton, 1958a, p. 27). Other alluvial deposits were on the Palombe plain between Lake Shirwa and Mlanje Peak (p. 27).

As previously mentioned, one of the sources of the detrital monazite at Monkey Bay has been said to be aplite dikes at Lungu Hill (p. 27), but as there are many varieties of bedrock in the drainage basin of Lake Nyasa, the detrital monazite probably has several sources. This monazite was stated to contain 6.2 percent of ThO_2 (South African Mining and Eng. Jour., 1956a). Although active prospecting of the Lake Nyasa beaches was under way in 1957, no deposits had been opened for production by 1958 (McNaughton, 1958b, p. 28).

GHANA

Monazite has been found in stream gravels in many parts of Ghana, but ordinarily it is one of the less common minerals. Kitson and Felton (1930, p. 13–48) discussed the mineralogy of 639 concentrates selected from a collection of 15,500 concentrates panned from alluvium, saprolite, and crushed rock by members of the Gold Coast Geological Survey (Junner, 1959, p. 1320). The report showed some interesting mineral associations in the 91 concentrates that are monazite bearing. The mineralogy of the monazite-bearing concentrates is tabulated in table 3, together with a summary of the geographic distribution of monazite, and the kinds of rocks represented by the concentrates. In five concentrates, monazite is the most abundant heavy mineral, and in six it is the 2d most abundant; generally, it is the 5th to 11th mineral in order of abundance. Where monazite is not the most abundant, it is preceded by one or more of the following: Zircon, magnetite, ilmenite, rutile, sillimanite, kyanite, staurolite, garnet, epidote, and tourmaline.

Magnetite, sillimanite, andalusite, staurolite, garnet, and sphene occur more frequently in monazite-bearing concentrates than in monazite-free concentrates (table 4). The increase in frequency of these minerals is related to the association of the monazite with granitic rocks and metamorphosed sandstone, graywacke, and shale. Kitson and Felton (1930, p. 9) showed the

TABLE 3.—*Relative abundance of minerals associated with monazite in concentrates from Ghana*

[After Kitson and Felton (1930, p. 5–48)]

	Birim													Ashanti Akim	
	Birrimian system—granite and dikes	Granite—dikes and Voltaian sand	Birrimian system containing dikes											Voltaian sand	Birrimian system(?)
Monazite	5	6	6	7	7	8	5	7	6	7	6	6	5	8	5
Zircon	3	1	1	6	2	2	1	1	1	1	1	1	3	4	3
Magnetite		3	2	3	4	4	2		4	4	5	3	1	1	1
Ilmenite	1		3	1	1	1	4	3	3	2	3		2	6	2
Rutile					6	5	7	5	9	8	4	9	7	5	7
Sillimanite								4		10					
Kyanite				5		7	8		10			2			
Andalusite		5								9	8				
Staurolite				2	9	6	9		8	5		8		9	6
Garnet			5		5			6	5			7		2	
Epidote	2	2		8	8	9	6	8	7	6	7	5	4	3	
Amphibole															
Spinel															
Sphene															
Tourmaline	4	4	4	4	3	3	3	2	2	3	2	4	6	7	4

	Accra					Cape Coast				Saltpond				Volta River	Tarkwa
	Granite and gneiss containing dikes					Birrimian system containing granite, gneiss, and dikes				Quartz vein in pegmatite	Granite and gneiss containing dikes			Granite and gneiss—dikes	Tarkwaian system(?)
Monazite	6	8	7	8	6	9	7	11	4	8	11	8	2	6	10
Zircon	5	5	3	3	3	4	3	3	1	4	2	1	3	3	5
Magnetite	3			1	1		2	2	3			5		1	1
Ilmenite		1	1	2	2	1	1	1	2	1	1	4	4	2	2
Rutile		9				7	5	9		7	7	7	5	7	7
Sillimanite	8	7	6	6		10					10		6		
Kyanite	7	3		7		5				5	5	6			4
Andalusite															
Staurolite						2		5	5	2	3				3
Garnet	4		5			3	4	4		3	4	2	1	5	9
Epidote	1	2	2	4	4	8		6	6		9	3			
Amphibole	2	6	4	5	5	6		7		6	8		7		
Spinel		4													8
Sphene		10					6	10	7			9			
Tourmaline								8			6			4	6

	Western Akim			Winneba			Mampong			Sunyani			Eastern Gonja		
	Tarkwaian system(?)			Birrimian system—dikes	Granite and gneiss containing dikes		Voltaian sand	Granite, gneiss, dikes and Voltaian sand		Birrimian system containing granite and dikes			Voltaian sand		
Monazite	5	6	9	11	3	6	3	12	3	5	6	8	11	8	9
Zircon	1	4	7	7	1	1	6	2	7	2	2	5	2	4	1
Magnetite		3	2	2			1	6	9	3	3		9	2	7
Ilmenite	2		1	1	2	2	2	5	4	1	1	1	4	1	2
Rutile		5	4	8		7	7	10	8	6	5	4	6		3
Sillimanite				9	5				6					10	
Kyanite			3					3			7	3	3	6	
Andalusite	4			10			8	11	5				8		
Staurolite	3		10	4			4	1	10			7	1	3	5
Garnet			8	5		3		4	2			2		5	
Epidote		1	6	13	4	4		8		4	4		10	7	4
Amphibole				3		5		7						9	
Spinel													5		8
Sphene				12	6										
Tourmaline		2	5	6			5	9	1			6	7		6

TABLE 3.—*Relative abundance of minerals associated with monazite in concentrates from Ghana*—Continued

	Western Dagomba		Kete Krachi	Ahafo-Goasa				Obuasi	Wenchi	Kusasi	Kumasi				
	Voltaian sand			Birrimian system and granite, gneiss, and dikes					Birrimian system and Voltaian sand	Quartz vein	Birrimian system and granite, gneiss, and dikes				
Monazite	7	10	9	10	5	11	7	8	7	3	9	10	6	5	8
Zircon	5	1	1	3		3	2	2	1	2	7	5	5	6	7
Magnetite	3	5	7			4	5		3	1	4	3	4	4	2
Ilmenite	4	3	2	7	1	1	1	1	4	4	6	2			4
Rutile		2	3	2		8		7	8	5	8	8	8		
Sillimanite						9		4				9			
Kyanite								5	6		3	4	7	8	6
Andalusite	1	4							5				9	7	
Staurolite		9	5	9		2	3	3		7	1	1	1	1	1
Garnet	2	7		4	4	6					5	6	3	3	3
Epidote	6	6	4	1	2	5				6					
Amphibole				5	3	7	6	6							
Spinel			8												
Sphene				8											
Tourmaline		8	6	6		10	4		2		2	7	2	2	5

	Kumasi—Continued Birrimian system and granite, gneiss, and dikes—Continued														
Monazite	1	6	2	1	2	1	1	2	1	5	3	6	6	2	3
Zircon	5	1	6	7	11	9	8	7	6	6	9	5	1	5	4
Magnetite	2	3	3	8	8	6	7		3	8	11	1	8	8	1
Ilmenite	3	7	7	5	3	2	5	1		4	7		5	1	2
Rutile			8		7	7	9	6		10	13			6	8
Sillimanite								9			2	4			
Kyanite	4	8		6	1	3				9	8		7		
Andalusite			9		6	10	6	8	4	7	4			7	6
Staurolite	6	2	4	2	4	4	2	4	2	2	1	2	2	3	5
Garnet	7	5	5	4	10	8	3	5	7	3	5	3	4		7
Epidote	8				9						12				
Amphibole															
Spinel											10				
Sphene															
Tourmaline		4	1	3	5	5	4	3	5	1	6	7	3	4	

	Kumasi—Continued															
	Birrimian system and granite, gneiss, and dikes—Continued			Birrimian system and granite, gneiss, and dikes and Voltaian sand									Voltaian sand			
Monazite	5	7	6	6	7	8	5	8	8	2	5	9	8	6	4	8
Zircon	1	4	2	5	4	5	4	5	4	1	1	1	1	1	3	1
Magnetite		1			8	6	7	4	6		9	5	7	5		7
Ilmenite	2	2	3	4	3	4	6	6	5	5	7	6	4	3	5	4
Rutile			4	8	6	7				4	6	7	6	2		2
Sillimanite			7	7				7	7							
Kyanite				3		9	8				3	3	3		2	5
Andalusite					5											
Staurolite	4	3	1	1	1	1	2	2	1	6	2	2	5		1	6
Garnet	6	5	5			2	1	1	2	7	8	8			6	
Epidote																
Amphibole																
Spinel	7				9		9				10	10	9			9
Sphene																
Tourmaline	3	6		2	2	3	3	3	3	3	4	4	2	4		3

TABLE 4.—*Frequency of mineral occurrence in concentrates from Ghana*

[Recalculated from Kitson and Felton (1930, p. 5–48)]

	Percent of concentrates containing mineral	
	91 monazite-bearing concentrates	*548 monazite-free concentrates*
Zircon	99	94
Magnetite	77	49
Ilmenite	91	91
Rutile	69	68
Sillimanite	25	3
Kyanite	46	37
Andalusite	27	8
Staurolite	74	49
Garnet	65	30
Epidote	44	37
Amphibole	21	24
Spinel	14	21
Sphene	9	2
Tourmaline	72	74

sillimanite, andalusite, staurolite, and garnet to be common detrital minerals in streams draining metamorphosed sedimentary rocks, and they reported the sphene to come from granite and pegmatite. Spinel and amphibole, which occur less commonly in the monazite-bearing concentrates than in the monazite-free concentrates, are indicated as coming from mafic and intermediate rocks.

Forty-four monazite-bearing concentrates came from areas in which metamorphic rocks of the Birrimian system, associated granitic rocks, and possibly older Precambrian gneisses are exposed. The Birrimian system is a geosynclinal sequence which consists of an older suite of phyllite, schist, graywacke, and tuff, and a younger suite of lavas and tuff containing subordinate phyllite and graywacke (Junner, 1938, p. 4).

Locally the Birrimian rocks reach the metamorphic rank of staurolite-garnet schist and kyanite-staurolite schist (Kitson and Felton, 1930, p. 6). Precambrian rocks older than the Birrimian system comprise hornblende and biotite gneisses, migmatites, granulites, and schists, some of which are garnetiferous. The Birrimian and older Precambrian rocks are intruded by large masses of foliated granite and granodiorite and small ones of massive soda-rich granite, granodiorite, and porphyry. Both groups of granitic rocks are Precambrian in age and are older than the overlying Tarkwaian sedimentary rocks.

The common association of kyanite, staurolite, garnet, andalusite, and epidote in monazite-bearing concentrates from regions underlain by the Birrimian system attests that the Birrimian rocks are metamorphosed to the albite-epidote-emphibolite facies and to the staurolite-kyanite subfacies (Turner, F. J., 1948, p. 76). Sillimanite schists and gneisses of the upper amphibolite and granulite facies seem to have formed locally in pre-Birrimian rocks and sillimanite schists of the amphibolite facies may have formed in the Birrimian rocks. Of the 639 concentrates reviewed by Kitson and Felton (1930, p. 13–48), 40 contain sillimanite, and 23 of these 40 are monazite bearing.

Of the 91 concentrates that Kitson and Felton reported monazite bearing, 41 are from samples taken in areas where the Voltaian sand, a pre-middle Devonian sequence of shale, mudstone, and sandstone, is exposed with granites and the metamorphosed sedimentary rocks of the Precambrian Birrimian system. Voltaian rocks cover 45 percent of the surface of Ghana. They are horizontal or gently inclined and are practically devoid of intrusive rocks and veins (Junner, 1938, p. 2–5). From the descriptions of the 41 concentrates, the relative roles of the Voltaian sediments and the Birrimian rocks as sources for the monazite cannot be determined. Mineralogical similarities between monazite-bearing concentrates panned from areas underlain by rocks of the Birrimian system and monazite-bearing concentrates derived from areas in which both Voltaian sands and Birrimian rocks are exposed suggest a dominant role for the Birrimian rocks and their associated granites.

Four monazite-bearing concentrates came from areas questionably underlain by the Tarkwaian system, a sequence of Precambrian rocks younger than the Birrimian system. The Tarkwaian rocks consist of a weakly metamorphosed basal conglomerate succeeded upward by quartzite and conglomerate, phyllite, and sandstone. Large sills of altered gabbro and small sills and dikes of granite and diabase intrude the Tarkwaian system (Junner, 1938, p. 4–5). Epidote, andalusite, and staurolite occur in these concentrates, but sillimanite is absent.

Of the 91 monazite-bearing concentrates, 2 came from quartz veins in pegmatite and granite. The distribution of the 91 monazite-bearing concentrates shows that in Ghana, monazite occurs locally in Precambrian migmatite, granulite, gneiss, and schist; these host rocks are of uppermost amphibolite facies and granulite facies (the pre-Birrimian rocks). Monazite is locally present in Birrimian schists that are of middle and lower amphibolite facies and in albite-epidote-amphibolite facies. This mineral is present in granite and pegmatite and in quartz veins in the Birrimian and pre-Birrimian rocks. It is possibly present in the slightly metamorphosed and feebly intruded younger Precambrian sedimentary rocks of the Tarkwaian system. Monazite may be an accessory mineral in the unmetamorphosed and virtually uninjected sedimentary rocks of pre-middle Devonian age known as the Voltaian sands.

Fine-grained muscovite granite near Asamang in the basin of the Pra River is the source of small amounts of monazite found in the stream gravels (Kitson, 1924a, p. 6). Accompanying the monazite are ilmenite, leucoxene, magnetite, hematite, limonite pseudomorphous after pyrite, epidote, tourmaline, zircon, garnet, and a few flakes of gold.

Near Foso, biotite schist crops out in the Nsuisen Su, and concentrates from the stream consist of kyanite, epidote, monazite(?), zircon, staurolite, garnet, rutile, ilmenite, magnetite, hematite, and a little gold (Kitson, 1924a, p. 7). Other streams in the same area also contain a little monazite, some of it doubtfully identified (Kitson, 1929a, p. 8).

Gravel in the Sirekuma Su near Apisim was the source of a staurolite-rich concentrate containing monazite(?), zircon, epidote, garnet, ilmenite, magnetite, and gold (Kitson, 1924a, p. 16). The stream flows on an area of biotite granite in which there are inclusions of metasedimentary rocks.

Decomposed biotite granite in the bank of the Tain River contains monazite, as does the streambed (Kitson, 1924a, p. 48).

Concentrates from stream sediments in the area between Kumasi and Chichiweri (Chichiwerri) and in the vicinity of Abofuo contain ilmenite, rutile, magnetite, hematite, garnet, zircon, staurolite, epidote, kyanite, monazite, schorl, and columbite and a little cassiterite and gold (Kitson, 1924b, p. 8). Underlying the area is foliated biotite-muscovite granite intruded by dikes of muscovite pegmatite.

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Sand in the Black Volta River near Saru was the source of concentrates that consisted of abundant rutile and some zircon, garnet, staurolite, kyanite, and epidote, a few specks of gold, and possible monazite (Kitson, 1924b, p. 21).

Porphyritic biotite granite exposed near Daboase intruded fine-grained biotite gneiss and hornblende-garnet gneiss, but it produced only slight metamorphism in the intruded rocks. Thin sections of the granite disclose that it contains monazite and allanite (Kitson, 1929b, p. 9).

A panned concentrate from a biotite pegmatite dike in biotite schist exposed 0.8 mile southeast of Nakwaby (Nakwabi) contained zircon, rutile, spinel(?), monazite(?), axinite(?), cassiterite(?), kyanite, magnetite, and schorl (Kitson, 1927, p. 15).

Small concentrates that were rich in monazite were obtained from weathered debris of granite and pegmatite in the vicinity of Chimera (Kitson, 1927, p. 43). Monazite is common in the gold placers in Ghana (Junner, 1938, p. 9).

Diamond placers in Ghana locally contain very small amounts of monazite. In their approximate order of abundance, the main heavy minerals in the placers are staurolite, ilmenite, limonite, rutile, and tourmaline. Generally present but sparse are zircon, magnetite, hematite, leucoxene, kyanite, andalusite, and pyrite. The scarce minerals are actinolite and tremolite, anthophyllite, sphene, epidote, anatase, monazite, apatite, chrysoberyl, corundum, gorceixite, xenotime, sillimanite, beryl, brookite, and cassiterite (Junner, 1943, p. 21). Except for a few places the monazite-bearing diamond placers are confined to streams in the vicinity of the granite near Manso, Supongo, and Osenasi. Diamond placers in the Bershea Su, a small stream 2 miles south of Kade, also contain monazite (Junner, 1935, p. 9).

Placer monazite from Kodiabe (Kotabebi), analyzed by E. H. Beard of the Imperial Institute in London (Junner and James, 1947, p. 54), contains 6.5 percent of ThO_2 and 61.47 percent of REO_2.

Chemical weathering in parts of Ghana extends to great depths in the wet-forest regions depth of weathering may be as much as 200 feet, and the decomposed rocks provide a ready supply of chemically resistant heavy minerals to the rivers that empty into the Gulf of Guinea. The rivers, in turn, might be expected to discharge monazite-bearing black sands into the gulf, where shore currents along the beach might further sort the heavy minerals; however, the concentrates from coastal sands described by Kitson and Felton (1930, p. 13) were devoid of monazite.

Monazite has not been mined in Ghana.

KENYA

Monazite, beryl, and rutile locally occur as accessory minerals in pegmatite dikes in the gneiss, granulite, schist, and orthogneiss of the Loldaika Mountains–Ngare Ndare area (Murray-Hughes, 1933, p. 5; Hitchen, 1937, p. 90).

Monazite was found in the early 1950's in carbonatite intrusives at Mrima Hill near the border with Tanganyika about 40 miles south of Mombasa. The carbonatite intrusives are exposed in an area of Permian and Triassic sedimentary rocks and apparently intrude them. The monazite contains less than 1 percent of ThO_2 (Pulfrey, 1947, p. 281–282; Davidson, 1956a, p. 206).

Monazite is a minor constituent of the black sands at the mouths of the Galana (Athi) River and the Tana River, which are streams that empty into the Indian Ocean (Pulfrey, 1947, p. 297; 1954, p. 25); it has been found on Patta Island (Hintze, 1922, p. 344). Monazite placers are likely to be found in streams that drain sillimanite gneisses and granulites of the Precambrian basement in the central and western part of the country and also in sedimentary rock of Jurassic to Recent age that overlie the gneisses in the eastern part of the colony (Pulfrey, 1947, p. 279, map).

LIBERIA

Monazite was said to occur in Liberia, but details were not given (Wallis, 1907).

MALAGASY REPUBLIC

CRYSTALLINE ROCKS, ELUVIUM, AND FLUVIAL SEDIMENTS

The distribution of monazite in the crystalline rocks, eluvium, and fluvial sediments of the Malagasy Republic was reviewed by Lacroix (1922, p. 344–351), H. W. Turner (1928, p. 70–76), and Besairie (1953, p. 20–147, sheets 3, 5, 6, 8–11, 13). Much of the following description is drawn from these reports.

Monazite occurs in the Malagasy Republic as an accessory mineral in kyanitic, sillimanitic, and cordierite-bearing fine-grained biotite gneisses (leptynites); coarse-grained mica schists and gneisses; quartz-poor aluminous schists of high metamorphic rank (lamboanites); migmatites, granites, pegmatites, and quartz veins. Local segregations of monazite have been observed in granites, and the mineral has been found disseminated in metamorphosed limestone at its contact with intrusive granite. No bedrock source has been commercially exploited for monazite. The crystalline rocks are deeply weathered, and erosion of the weathered bedrock has released monazite into stream sediments of Quaternary age. Some of these sedimentary deposits may prove to be exploitable placers.

Monazite is so common in the rocks of the island that it was found in at least 90 percent of the 10,500 concentrates studied by the Service Géologique [Madagascar] in 1955 (Behier, 1955, p. 140).

Systematic studies of 964 concentrates from streams in the Ankaizina Mountains in the northern part of the island disclosed local deposits of monazite north of Antsaonjo and on the east flank of Analabe Berohitry (Emberger, 1956, p. 53–54). Around Antsaonjo the raw sand contained 0.01–1 percent of monazite, but most of it had 0.03 percent. A placer extending 2 miles along a stream northwest of Antsaonjo was estimated to contain a ton of monazite at a concentration equal to 1 percent of the alluvium (Emberger, 1956, p. 54). The richest stream deposits along the east flank of Analabe Berohitry contain as much as 0.8 percent of monazite, but the reserves are said to be economically insignificant.

To the northeast and adjacent to the contract between two-mica granite and garnet-sillimanite gneiss in the vicinity of Mananjeba, the streams are commonly monazite bearing, and concentrates from their alluvium contain 6–48 percent of monazite (Saint-Ours, 1956, p. 27). Monazite in the gravel, however, was said not to exceed 0.3 percent by weight. Monazite from the Mananjeba River was said to contain 4.1 percent of ThO_2 (Behier, 1960, p. 50). Around Marotolana in a region of migmatites having no visible granite, monazite is present in the streams, but high-tenor deposits had not been found as of 1956 (Saint-Ours, 1956, p. 27).

Granitic and syenitic pegmatites have furnished large well-formed crystals of monazite for mineralogical study, but, like pegmatites elsewhere in the world, they contain no economic concentrations of monazite. Pegmatites in the south-central part of the island are noteworthy for their monazite crystals. Between Miandrarivo and Mandoto, especially between Ankisabe and Soarivola and around Ambatofotsikely (Duparc and others, 1913, p. 5–8; Ungemach, 1916, p. 19; Lacroix, 1922, p. 347; H. W. Turner, 1928, p. 76; Besairie, 1953, p. 54), monazite is associated with muscovite, beryl, almandine-spessartite, columbite, ampangabeite, ilmenorutile, strüvérite, allanite, malacon, orangite, and uranothorite in a broad zone of uraniferous pegmatites in gneiss and migmatite. Analyses of monazite from two pegmatites at Miandrarivo and Ambatofotsikely, which had respective specific gravities of 5.11 and 5.27, showed that the monazite had the following composition:

[Analysts: *A*, F. Pisani (in Lacroix, 1922, p. 351); *B*, Duparc, Sabot, and Wunder (1913, p. 8). See also Arthur Holmes (1931, p. 374).]

	Percent	
	A	*B*
Ce_2O_3	31.85	26.95
La_2O_3 (group)	27.90	32.60
$(Y, Er)_2O_3$	2.93	.30
ThO_2	9.15	11.23
P_2O_5	27.45	25.90
SiO_2	------	2.87
Al_2O_3	.21	.15
Fe_2O_3	.42	.60
ZrO_2	------	.11
Ta_2O_5	------	.24
CaO	------	Trace
Loss on ignition	.74	.56
Total	100.65	101.51

A. East of Miandrarivo.
B. Ambatofotsikely.

A zone of beryl- and muscovite-bearing pegmatites lies southwest of Miandrarivo in the Ampandramaika-Malakialina area (Guigues, 1955, p. 43, 49). The pegmatites are in kyanite- and sillimanite-bearing mica schists on the northwest side of granite exposed between Ihorombe and Ambararata. The pegmatites contain few accessory minerals and little monazite. Placer monazite is of such small consequence that it could only be a byproduct of mining for columbite-tantalite. Monazite is particularly abundant, however, in the granitic rocks of the Ihorombe-Ambararata area, and streams rising there are rich in monazite. Sediments in the upper valley of the Belobaka River contain as much as 8 percent of monazite, and some sediments from the Manatsahala River (Manantsahala River) contain 5 percent of monazite (Besairie, 1953, p. 82).

Huge monazite crystals have been found in syenitic and granitic pegmatites around Itrongay in the southwestern part of the island south of Ambararata and southwest of Betroka. The pegmatites are in gneiss and leptynite. Associated with the monazite are crystals of translucent yellow orthoclase, translucent diopside, clear green kornerupine, zircon, chevkinite, and euxenite. Strongly radioactive, monazite-bearing alluvial sediments have been deposited throughout the pegmatite district (Besairie, 1953, p. 114).

The Berere pegmatite field is a source of commercial beryl and columbite, and monazite is an associated accessory mineral (Giraud, 1957, p. 125, 130). The country rocks are pyroxene and amphibole gneisses, which to the west overlie migmatite. An external halo of biotite pegmatites surrounds the field and gives way inwardly to a band of two-mica pegmatites. Muscovite pegmatites occupy the center of the field. Monazite is a very minor accessory mineral in the muscovite pegmatites, which are composed of quartz, perthite, albite, muscovite, biotite, garnet, beryl, and columbite. It is more common in the two-mica pegmatites, which consist of quartz, albite, muscovite, biotite, garnet, euxenite, ampangabeite, allanite, zenotime, and zircon. It is a common accessory mineral in the biotite pegmatites, which consists of quartz, perthite, biotite, garnet, very scarce beryl, fergusonite, samarskite, magnetite, and thorite.

Beryl-bearing potassic pegmatites in gneisses, migmatites, and granites around Mount Vohambohitra in the Ankozobe and Anjozorobe districts of the north-central part of the island contain accessory monazite, samarskite, fergusonite, and strüvérite (Lacroix, 1922, p. 345, 349; Giraud, 1955, p. 39–40). Giraud (p. 42) suggested that monazite could be recovered as a byproduct from the mining of fergusonite in the Mount Vohambohitra area. A granitic pegmatite on Mount Vohambohitra, lacking beryl and uranium minerals, contains monazite which has 8.9 percent of ThO_2. Elsewhere in the area monazite accompanies columbite-tantalite in zones of kaolinized perthite at the contact of veinlets of smoky quartz with pegmatite (Behier, 1955, p. 140).

In the extreme northwestern part of the island, a west-flowing stream called the Andranomalaza rises along a contact between granite and gneiss and empties in the Baie de Sahamalaza (Baie de Port Radama). Sedimentary deposits of this stream are monazite bearing (Besairie, 1936, p. 228).

Monazite crystals have been collected from eluvium derived from bastnaesite- and chevkinite-bearing pegmatites in granite gneiss at Ambahy in the south-central part of the island west of Finandrahana (Lacroix, 1922, p. 349; Besairie, 1953, p. 89).

Beryl-bearing pegmatite veins at Tongafeno near Betafo contain monazite and hatchettolite (Lacroix, 1911, p. 561). This is the first locality where primary monazite was found in the Malagasy Republic, its presence in this locality being predicted by Lacroix (1909) in his discussion of monazite-rich gold placers.

Monazite crystals are associated with hatchettolite and blomstrandine in rose quartz that is quarried between Betafo and Antsirabe in central Malagasy (Hintze, 1922, p. 344). Monazite was reported to occur in the alluvium at Antsirabe (Holmes and Cahen, 1955, p. 26). Monazite from an undescribed source at Ampangabe contains 15.38 percent of ThO_2 (H. W. Turner, 1928, p. 82).

Monazite from Morarano to the northeast of Tananarive was reported to be nonradioactive; its source was not described (H. W. Turner, 1928, p. 82).

Pegmatites consisting of graphic intergrowths of quartz and perthite and some biotite occur in biotite gneiss near Befanamo (Guigues, 1954, p. 69–70). Dispersed lenticles of quartz, perthite, beryl, muscovite, columbite-tantalite, and thortveitite in the pegmatites contain small amounts of monazite. The probable order of crystallization was beryl, columbite-tantalite, fergusonite, euxenite, and monazite, then stüvérite and thortveitite, and last zircon and xenotime(?). At Miarinkofeno 2 miles northwest of Befanamo, monazite is abundant in veins of pegmatite that is similar to the pegmatites at Befanamo. About 5 miles northeast of Maharidaza, veins of pegmatite conform to the layering in amphibolite; they contain sheet muscovite, biotite, monazite, magnetite, garnet, tourmaline, beryl, and columbite. These veins of pegmatite are described as being particularly rich in monazite (Guigues, 1954, p. 70). Eluvial placers are derived from the pegmatite.

Fine-grained accessory monazite occurs in cordierite lamboanite at Ankaditany near Zazafotsy in the extreme south-central part of the island (Lacroix, 1956, p. 8).

Monazite is a normal accessory mineral, but also occurs as lodes and segregations, in an ancient granite in the extreme southeastern part of the island north of Fort-Dauphin (Besairie, 1948, p. 120; 1953, p. 146). Locally the concentrations are high, but they are of small size and not economic (Lecoq, 1957, p. 592).

Imerinite-bearing metamorphosed banded limestone that is exposed at Ambatoarina, east of Ambatofangehana in the central part of the island, contains microscopic, disseminated crystals of yellow monazite. This limestone is intruded by granite and by veins of calcite pegmatite composed of calcite, quartz, microcline, albite, celestite, ambatoarinite, and monazite. Tiny crystals of monazite occur as an accessory in the granite, but in the calcite pegmatite the grains of monazite are as much as 1 millimeter across and tend to aggregate into granular masses. Monazite having a specific gravity of 5.25 was recovered from eluvial soil trapped in cavities in the metamorphosed limestone and was analyzed and found to have the following composition (Lacroix, 1922, p. 349-351).

	Percent
Ce_2O_3	39.51
$(La, Di)_2O_3$	27.80
ThO_2	1.05
P_2O_5	30.18
Fe_2O_3	.92
CaO	.46
Loss on ignition	.47
Total	100.39

Detrital monazite has been found in streams in the eastern interior and along the east coast of the Malagasy Republic from as far north as Presqu'ile Masoala southward to Fort-Dauphin and thence westward to the Baie des Gallions. Throughout much of this tract, monazite also is found in beach sands. Both the frequency with which fluvial concentrates contain monazite and the amount of monazite they contain along the east side of the island increases southward from Presqu'ile Masoala. This southward increase in the abundance of monazite seems to parallel a southward increase in the plutonic character of the crystalline rocks. Around Presqu'ile Masoala, the Baie d'Antongil, and southward for some 20 miles, granite intrudes schists and is filled with inclusions of schist. The inclusions and wallrocks rise in metamorphic facies from chloritic and micaceous schists in the northern part to kyanitic mica schists in the central and southern parts of the area. At the north end of the granite, near Maroantsetra, where chloritic and micaceous schists are present, only 4 out of 10 concentrates from stream sediments contained monazite (Besairie, 1953, p. 20). Monazite was found, however, in 35 out of 51 concentrates (68 percent) from stream sediments in the central and southern parts of the granite between Mananara and Pointe à Larrée where kyanitic rocks are present (Besairie, 1953, p. 34). Streams draining kyanitic gneisses and schists near Fenerive and Vavatenina south of the granite were the sources of 67 concentrates, of which 50 (74 percent) had monazite (Besairie, 1953, p. 38).

The mica schists and gneisses along the east side of the island become increasingly plutonic in character south of Fenerive and Vavatenina. Sillimanite and corundum occur, and in the interior of the island west of Vavatenina, a zone of granitic migmatite crops out and extends southward. Farther south in the Ampasinambo region west and northwest of Mananjary, a zone of granitic migmatite is found in kyanitic and sillimanitic gneisses and schists, and monazite is common in sediments along all the streams in the area (Besairie, 1953, p. 94; Saint-Ours, 1955, p. 23). The greatest concentrations of monazite are in gold placers along the Ampasary River between Ambalavia and Antanamboa. Southeast of the Ampasary River in the drainage basin of the Mananjary River, where monazite mining has been attempted (Besairie, 1953, p. 101; H. W. Turner, 1928, p. 82), small round grains of monazite, apparently derived from the gneisses of the district, are common in most of the streams and are especially abundant in the Saka River. Monazite from the Mananjary River contains 8.6 percent of ThO_2 (Behier, 1960, p. 50). The detrital monazite from the Saka River contains 9.0–10.0 percent of ThO_2 (Lacroix, 1922, p. 350–351). Accompanying monazite in the Mananjary River and its tributaries are detrital kyanite, sillimanite, staurolite, corundum, rutile, almandine, hornblende, augite, magnetite, ilmenite, zircon, and gold (Lacroix, 1909, p. 314). Clean monazite from the mouth of the Mananjary River contains 10 percent of ThO_2 (Lacroix, 1909, p. 317).

Sillimanite quartzites and gneisses, garnetiferous leptynites, cordierite leptynites, and vast zones of migmatite which has bands of graphite occupy the central and eastern parts of the island and extend south from the Ampasary basin to the vicinity of Fort-Dauphin where ancient granites are exposed. Sediments in streams throughout this region contain monazite. Sand at the mouth of the Mananara River east of Vangaindrano has abundant monazite (Besairie, 1953, p. 126), and thorium-rich monazite occurs in almost every stream in the southern and southeastern parts of the Malagasy Republic (Besairie, 1948, p. 120).

The rocks in the extreme southeastern part of the island are of the granulite facies of regional metamorphism (Roche and Marchal, 1956, p. 142–144; Besairie, 1954, p. 107, 110; Behier, 1960, p. 50) and are highly migmatized and granitized in many places. Phlogopite and thorianite occur in the diopside pyroxenites, and monazite and apatite occur in intragranitic lentils in which the monazite makes up as much as 30 percent of the lentil. Iron-rich layers contain garnet, spinel, sillimanite, magnetite, hypersthene, and phlogopite in association with arsenopyrite, monazite, and cassiterite.

Many of the mineralized lentils are masked by eluvium; thus, their sizes have not been well defined (Roche and others, 1956, p. 154–156). Because the monazite-apatite lentils resemble the great monazite-apatite vein at Steenkampskraal in South Africa, considerable attention has been paid to the possible occurrence of a large deposit in the granulites of the southeastern part of the Malagasy Republic, but as of 1960 none had been reported. The monazite-apatite veins northwest of Fort-Dauphin contain reserves of 35–80 tons of monazite each. In addition to segregations of monazite and apatite in granitic rocks, smaller deposits of monazite segregated with other minerals have been found in ferromagnesian rocks. The segregations include biotite and monazite; ilmenite, apatite, and monazite; ilmenite, zircon, and monazite; phlogopite, apatite, and monazite; and garnet, monazite, and apatite. The following chemical composition of monazite from the monazite-apatite metamorphic differentiation assemblages was determined by P. Rose (Roche and others, 1956, p. 156):

	ThO_2	RE_2O_3
Manangotry assemblages:		
1	12.37	55.81
2	10.28	57.66
3	6.46	59.40
Ampasimena assemblages:		
1	7.77	57.70
2	5.28	62.28

Another analysis of monazite from pegmatite at Ampasimena was given by Behier (1960, p. 50); this analysis showed 1.83 percent of ThO_2 and 63.65 percent of REO_2. Monazite from granite in the vicinity of Vohimena contains 7.8 percent of ThO_2 (Behier, 1960, p. 50).

LITTORAL DEPOSITS

Beach placers have not been prospected from Fenerive northward along the northeast shore of the Malagasy Republic, but some monazite probably occurs in ilmenite placers north of Pointe à Larrée (Besairie, 1953, p. 21, 44). To the south, beach sands between Vatomandry and Manakara were reported (Harris and Trought, 1952, p. 48) to contain as much as 2 percent of monazite. This stretch of beach is flanked by basalt flows of Cretaceous age that extend southward nearly to Manantenina, but monazite was reported (Lacroix, 1909, p. 317; Besairie, 1953, p. 101, 126) to be deposited at the mouths of the Mananjary and Mananara Rivers and to be concentrated along the beaches south of the Mananara River. Between the mouth of the Mananara River and Manantenina, the basalt flows pinch out and from the bay at Manantenina southward to the Baie des Gallions, extensive prospecting on the beaches has revealed placers that are rich in monazite and zircon (Lamcke, 1937, p. 117; Besairie, 1953, p. 146; Roche and others, 1956, p. 147; Lecoq, 1957, p. 591; Behier, 1960, p. 50).

Descriptions of the monazite placers on the southeast coast of the Malagasy Republic from the mouth of the Mananara River to the beaches west of Fort-Dauphin were given by Roche, Marchal, and Delbos (1956, p. 147–152), and they are summarized in the following text. Marine sands form a belt 1000–5000 feet wide along the southeast coast. Locally the belt may be broken by rocky promontories, or widened at the mouths of rivers, or extended by dune systems. In the vicinity of Fort-Dauphin, rocky capes and bays are bordered by marine sand which extends several miles inland. Some beaches form a zone 35–160 feet wide upon which the surf falls, and there monazite may become highly concentrated. Ancient raised beaches lie between the present beaches and the first dunes. These ancient beaches have a barren overburden beneath which rich placers are buried. The dunes are classed as modern and old. Modern dunes are composed of white sand, are barren or nearly barren of vegetation, and form low-tenor deposits of large volume. Old dunes are weathered yellow or red and have rubified and consolidated sand at the base, a bleached surface, and diverse fixed vegetation. Placers in the old dunes are less rich than the beaches but they uniformly contain 25–30 percent of heavy minerals, of which 1.2–1.5 percent is monazite, and they are of enormous volume. More than 80 percent of known reserves are in the old dunes.

Eleven of the present beaches south of the mouth of the Mananara River were explored (Roche and others, 1956, p. 151). Total estimated tonnage of black sand is 110,000 short tons of which 3,000 short tons is monazite, 4,000 short tons zircon, and 88,000 short tons ilmenite. Two deposits, one known as the Bofasy-Ilanamainty and the other as the Fort-Dauphin, contain 80 percent of the reserves.

Sixteen old beach and dune deposits were explored in the same stretch of coast and were reported (Roche and others, 1956, p. 152–153) to contain 2,700,000 short tons of black sand in which there are 35,000 short tons of monazite, 44,000 short tons of zircon, and 770,000 short tons of ilmenite. The ilmenite contains 50.7–57.9 percent of TiO_2 with traces of chromite. Analyses of beach and dune sands from the area are given in table 5.

An analysis of monazite sand from an unspecified locality in the Malagasy Republic is given by Hintze

TABLE 5.—*Thorium and rare-earth content of monazite from beach and dune placers along the southeast coast of the Malagasy Republic*

[Analyst: P. Rose (in Roche and others, 1956, p. 153) and F. Ruf (in Behier, 1960, p. 50). Size of deposit: Large, estimated more than 5,500 short tons of monazite; Medium, estimated ±1,100 short tons of monazite; Small, estimated 200–700 short tons of monazite]

	Kind of deposit	Size of deposit	ThO_2	RE_2O_3
Vangaindrano, mouth of Mananara River.	Beach	No data	7.38	57.40
Ambalafandra	do	Small	7.25	52.30
Ilanamainty (Befasy)	do	Large	7.45	56.60
Ambinan'Andringitra	Dune	Small	7.70	59.86
Vohibarika:				
North	Beach	Large	6.84	59.16
West	do	Large	7.88	59.02
South	do	Large	9.04	58.46
Manambato	No data	Small	7.52	58.63
Ihabakoho	No data	do	5.90	62.78
Fort-Dauphin (Abattoir)	Beach	Large	6.68	56.92
Ambasivasy	Dune	Medium	9.0	57.5
Amboangitelo	No data	No data	5.28	62.28
Ranomainty-Vangaindrano	Beach	No data	9.07	57.86
Papango	do	No data	8.64	57.82
Ikalomanga	do	No data	9.44	57.71
Ampasimeloka:				
North	do	No data	7.40	56.00
South	do	No data	7.05	57.00

(1922, p. 370) as having 5.5 percent of ThO_2. The sample seems to have been a mixture of minerals, including quartz, several percent of rutile and zircon, and nearly 10 percent of ilmenite. Monazite in this mixture could have at least 6.9 percent of ThO_2.

Beach sands at a locality called the Abattoir on the west side of Fort-Dauphin were discovered by the Commissariat à l'Energie Atomique and were mined and processed from 1954 by the Société des Monazites de Madagascar (Lecoq, 1957, p. 591). Rare earths and thorium were separated from the monazite, the rare earths going to the company and the thorium to the C.E.A. In 1956 the output from Abattoir was about 220 short tons of monazite. This monazite contains about 8 percent of thorium oxide.

In 1923 the national output of monazite from fluvial placers in the Malagasy Republic was 1.6 short tons (Turner, H. W., 1928, p. 82), and in the first quarter of 1924 exports of euxenite and monazite were 1.3 short tons (Madagascar Direction des Mines, 1924). Monazite production in the Malagasy Republic between 1955 and 1961 was said by John G. Parker (written commun., 1962), U.S. Bureau of Mines, to have been as follows:

	Short tons
1955	72
1956	168
1957	331
1960	471
1961	503

Along the west side of the island, monazite has been discovered only at Anakao where marine beach and dune sands that are very rich in garnet contain a little monazite (Besairie, 1953, p. 111).

MAURITANIA

Dune and beach sands along the Atlantic coast are locally monazite-bearing from Saint-Louis in the south to Port-Étienne in the north (Dropsy, 1943, p. 251–262). Sand at Sbar contains 6 percent of heavy minerals dominated by ilmenite but including garnet, zircon, tourmaline, monazite, topaz, and barite. Sand from stable dunes at Nouakchott (Nouak-Chott) has some ilmenite and zircon and a few grains of tourmaline, monazite, garnet, staurolite, and barite. White dune sand at Lemsid contains ilmenite, monazite, zircon, and sparse garnet, staurolite, and tourmaline. Beach sand at El Memrhar (El Manghar) is unusually rich in heavy minerals. It consists of 50 percent of quartz, 45 percent of ilmenite, and 5 percent of zircon and garnet; a little sphene, some magnetite, and very sparse monazite are also present.

MOZAMBIQUE

Few descriptions of monazite in Mozambique have been published, and apparently little has been done to explore for it (South African Mining Eng. Jour., 1947, p. 771). It was said to be found within a radius of 30 miles of Tete, but the mode of occurrence was not specified (Mining Jour., 1949).

The pegmatites at Alto Ligonha are monazite bearing and are the most frequently described monazite localities in the country, but they are not economic sources of monazite (Marble, 1948, p. 26; Hutchinson and Claus, 1956, p. 757–759; Bettencourt Dias, 1957, p. 279). Monazite is found with columbite, beryl, lepidolite, and bismuth in strongly zoned pegmatites in Precambrian quartz-biotite schist, quartz-muscovite schist, amphibolite, and granitic gneiss of medium to high metamorphic rank. Pegmatites in the schists are more likely to have monazite than pegmatites in the granite gneisses. An analysis showed that monazite having a specific gravity of 5.22 from a pegmatite at Boa Esperança in the Alto Ligonha district had the following composition:

[Analyst: Sousa Torres (1952, p. 189–190)]

	Percent		*Percent*
Ce_2O_3	24.30	TiO_2	0.97
La_2O_3	25.34	SnO_2	Trace
Y_2O_3	1.53	CaO	1.60
ThO_2	9.84	MgO	.65
U_3O_8	.00	PbO	Trace
P_2O_5	27.35	MnO	.98
SiO_2	5.76	H_2O	.35
Al_2O_3	.12		
Fe_2O_3	1.04	Total	99.83

Massive monazite-bearing pegmatites are widely exposed in the drainage basins of streams in the Ribawe Mountains (Holmes, Arthur, 1917, p. 40; 1931, p. 372). The region is underlain by biotite gneiss, hornblende gneiss, gneissic and porphyritic granite, marble, biotite granite, and augite granite. Heavy-mineral residues from the gneissic granite and biotite gneiss do not contain monazite, but alluvium in the Bwibwi, Sawa, Matupa, and Nrassi Rivers is locally monazite bearing (table 6).

The beach sand between Mozambique (Moçambique) and Quelimane was reported to have concentrations of heavy minerals among which are monazite, rutile, zircon, columbite, euxenite, and samarskite (Mining World, 1954). Monazite is present in the sand at the mouth of the Rovuma River (Ruvuma River) on the border with Tanganyika. As much as 1 percent of the black sand at Vila Luiza (Marracuene) is monazite (Davidson, 1956a, p. 202). This monazite was said to contain 5 percent of ThO_2.

TABLE 6.—*Mineralogical composition of monazite-bearing concentrates from streams in the Ribawe Mountain area, Mozambique*

[Arthur Holmes (1917, p. 83, table 10). Symbols used: A, abundant; C, common; R, rare]

	1	2	3	4	5	6	7
Magnetite	C	C	C	C	C	A	C
Ilmenite	A	A	A	A	A	A	A
Garnet	R	R	R	R	C	R	C
Zircon	A	A	A	A	A	A	C
Rutile	R	R	R	R	R	R	C
Monazite	R	R	R	C	C	R	R
Spinel	R	R	R	R	R	----	
Sphene	----	R	R	R	----	----	C
Apatite	R	R	R	R	R	R	C

1. Sawa River.
2. Bwibwi River below confluence with the Sawa River.
3. Bwibwi River below mouth of a tributary from Mount Tipwi.
4. Matupa River at Matupa Pass, Ribawe Mountains.
5. Bwibwi River above confluence of the Potela Mazi.
6. Nrassi River.
7. Nrassi River.

Although the origin of the monazite is unknown, the following output was reported from Mozambique (J. G. Parker, written commun., 1962):

	Short tons
1957	0.5
1958	.1
1960	1.0
1961	.2

NIGERIA

Detrital monazite was known to be present in Nigeria at least as early as 1902, and within the following decade its distribution, especially its association with tin (cassiterite) deposits, was reasonably well defined (Comité de l'Afrique Française, 1904; Chemische Zeitschrift, 1904; Dunstan, W. R., 1906a, p. 7–8; 1912, p. 7; 1913, p. 12; Falconer, 1912, p. 544).

Monazite is a fairly common accessory mineral in concentrates from tin placers in the Plateau Province of northern Nigeria, but in only a few places does it make up as much as 5 percent of the concentrate. Thorite, in abundances that are as much as 1 percent of the concentrate, occurs with the monazite and cassiterite. Ilmenite, columbite, zircon, garnet, and wolframite are present. Rutile and magnetite are scarce (Mackay and others, 1949, p. 13, 15). The principal source of the monazite in the Plateau tin fields is Precambrian metasedimentary rocks consisting of migmatite, biotite gneiss, granitic gneiss, calc-silicate rock, and quartzite of probably the upper amphibolite facies. A lesser source is the granites of metamorphic derivation emplaced in the Precambrian gneisses. These rocks contain a scant amount of columbite and no thorite or cassiterite, minerals which are related to a group of younger intrusives including pyrochlore-bearing riebeckite granite, biotite granite, greisen, and tin veins (Mackay and others, 1949, p. 13–57). In central Nigeria, monazite is found in cassiterite- and columbite-bearing eluvial placers and pegmatites associated with granites that resemble the old granites of northern Nigeria (Imperial Inst. London, 1947). Alluvial monazite has been found at many places in southern Nigeria, but no littoral or deltaic placers have been reported from the coast or the mouths of the Niger River.

Early mineral surveys reported monazite in concentrates of alluvium from several places in the Oban Hills and the northern part of Calabar Province where crystalline rocks rise above the coastal swamps and the belt of Cretaceous and younger sedimentary rocks (Dunstan, W. R., 1906a, p. 7–31; Raeburn, 1927a, p. 73). In this area, old quartz-mica schists, hornblende schist and gneiss, and gneissic porphyritic biotite granite associated with pegmatite are intruded by syenite, basalt, and diabase. Monazite-bearing alluvial sediments do not form large deposits. They are confined to the present channels of the streams, and most are small pockets deposited on scoured rock flanked by low, bare, rocky cliffs. Data from these early surveys are given in table 7. Later search revealed that monazite was most abundant in the Netim-Ibum triangle, the Okarara district, the Akwa Ibame cassiterite area, and in the Kwa River, but none of the deposits is of commercial size and grade (Raeburn, 1927a, p. 85–86). Composition of concentrates from the Calabar area is given in table 8.

TABLE 7.—*Mineralogical composition of monazite-bearing concentrates from streams in the Oban Hills area, Nigeria*

[Compiled from W. R. Dunstan (1906a, p. 11–31). Symbols used: A, abundant; C, common; S, scarce; Tr., trace; P, present]

	1	2	3	4	5	6	7	8	9	10
Monazite	Tr.	A	A	A	A	C	S	C	A	A
Ilmenite	P	P	P	P	P	P	P	P	P	
Magnetite	P	----	----	----	----	----	----	----	----	
Garnet	P	----	----	----	----	----	P	P	P	
Zircon	P	P	P	P	P	----	P	P	P	
Hornblende	P	----	----	----	----	----	P	P	----	
Tourmaline	P	----	----	----	----	----	P	P	----	
Gold	----	P	----	----	----	----	P	----	----	
Cassiterite	----	----	----	----	----	P	P	----	----	
Staurolite	----	----	----	----	----	----	P	----	----	
Rutile	----	----	----	----	----	----	P	P	----	
Columbite	----	----	----	----	----	----	P	P	----	
Corundum	----	----	----	----	----	----	----	----	P	

1. About 10 miles north of Obong.
2. Tributary to Ukpong River. 6.49 percent ThO_2 in concentrate.
3. Ukpong River northeast of Ibum. 4.20 percent ThO_2 in concentrate.
4. Creek southeast of Ibum. 5.18 percent ThO_2 in concentrate.
5. Ibum-Nsan path 6 miles south of Ibum. 5.34 percent ThO_2 in concentrate.
6. Calabar River upstream from the Iyanyita River.
7. Uwet district (87 concentrates).
8. Oban Hills (60 concentrates).
9. Netim-Ibum path, near Calabar River (4 concentrates).
10. Ibum (3 concentrates).

Eight chemical analyses of monazite concentrates of variable purity were given by W. R. Dunstan (1906a, p. 12, 13, 30, 31). They showed from 3.18 to 6.49 percent of ThO_2 in material containing from 65

TABLE 8.—*Mineralogical composition of monazite-bearing concentrates from streams in the Calabar area, Nigeria*

[Modified from analyses by Raeburn (1927a, p. 87). Symbols used: VA, very abundant; A, abundant; C, common; S, scarce; VS, very scarce]

	1	2	3	4	5	6	7	8	9	10	11	12
Ilmenite	C	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA	VA
Magnetite	S	------	------	C	S	C	S	------	------	VS	C	C
Rutile	------	VS	S	VS	------	VS	VS	------	VS	VS	------	VS
Tourmaline	A	C	C	------	------	S	VS	S	------	C	S	S
Cassiterite	VA	------	------	------	------	------	------	------	------	------	S	
Garnet	A	A	A	------	C	S	C	C	A	A	C	S
Epidote	VS	------	------	------	------	S	------	------	------	------	VS	VS
Monazite	C	S	C	S	S	S	A	VS	S	S	A	A
Sillimanite	------	------	VS	------	------	S	------	------	------	------	------	
Zircon	------	------	S	A	A	C	A	------	C	VS	A	A
Apatite	------	------	------	C	C	------	------	------	------	------	------	
Anatase	------	------	------	VS	------	------	------	------	------	------	------	
Gold	------	VS	VS	------	------	------	------	------	VS	------	------	

1. Uyana Ikpofia.
2. Kwa River at Oban-Nsan road.
3. Ebara River at Oban-Nsan road.
4. Niaji, at the Upper Enimayip.
5. Niaji, the Middle Enimayip.
6. Niaji, the Lower Enimayip.
7. Ndebbiji, lower Ikai Creek.
8. Ndebbiji, Ikpan River.
9. Oban, third creek on Okarara road.
10. Oban, Mango River.
11. Obutong, Lower Kinikhe Creek.
12. Obutong, Upper Kinikhe Creek.

to 99 percent of monazite and indicate that monazite from the Oban Hills has from 4 to 7 percent of ThO_2. Johnstone (1914, p. 57; 1918, p. 375; Imperial Inst. [London], 1914a, p. 59) reported that many analyses of monazite from southern Nigeria gave an average content of 5.8 percent of ThO_2 and that analyses from northern Nigeria gave an average content of 5.5 percent. Six of these analyses are given in table 9.

TABLE 9.—*Chemical analyses, in percent, of monazite from Nigeria*

[Analyst: Johnstone (1914, p. 57)]

	1	2	3	4	5	6
Ce_2O_3	30.72	36.53	30.50	30.38	34.58	31.40
La_2O_3 (group)	30.02	30.00	28.80	29.60	29.83	29.20
Y_2O_3 (group)	2.74	.39	1.43	1.33	1.29	2.00
ThO_2	5.00	3.20	8.00	6.19	2.30	5.50
P_2O_5	26.29	28.29	28.16	29.70	29.71	29.92
SiO_2	1.20	.63	1.79	.85	.73	.82
Al_2O_3	.35	.10	.20	.10	------	.05
Fe_2O_3	3.00	1.20	.81	1.50	1.80	.75
CaO	.15	.21	.17	.16	.19	.10
Loss on ignition	.25	.20	.21	.33	.21	.44

Northern Nigeria:
1. Ekole.
2. Kadera.
3. Jarawa River, Naraguta.

Southern Nigeria:
4. Iboboto stream, Nsan-Oban trail.
5. Between Iboboto stream and Ebara River.
6. Ebara River.

Concentrates from a creek at Okpudu and from Oyi stream in the Abagana district northwest of the Oban Hills contain less than 1 percent of monazite (Dunstan, W. R., 1913, p. 12). Minable deposits are unknown in the district.

Several streams in the vicinity of Benin City were said to be monazite bearing, but here also the monazite makes up less than 1 percent of the concentrate (Dunstan, W. R., 1912, p. 7). Associated with the monazite are abundant zircon and ilmenite and sparse rutile, staurolite, kyanite, tourmaline, garnet, and magnetite. Occurrences are at Eleru stream near Siluko, the stream heading between Okwa and Igolaw, Abega stream, Ikpoba River, Ohuma River, Ohi River, Oroghodo River (Orogodo stream) at Agbor, and Nyama stream.

Cassiterite-tantalite concentrates from streams between Wamba in Plateau Province and Egbe in Kabba Province invariably contain green to greenish-brown monazite. Although monazite has been identified in only a very few pegmatite dikes in the region, it is thought to have come from them (Jacobson and Webb, 1946, p. 23). In the paragenetic sequence for these dikes as interpreted by Jacobson and Webb, monazite, together with other phosphate minerals, was questionably assigned a narrow range between the pegmatitic and hydrothermal stages when highly differentiated solutions crystallized to form complex pegmatites with or without replacement.

Monazite is a minor but constantly present mineral in concentrates from cassiterite placers in the Mama area in Nassawara Province (Raeburn, 1926, p. 17). Ilmenite and rutile are the most abundant minerals in the concentrates (table 10). None of the placers is an economic source for monazite.

The Mama area is underlain by biotite gneiss intruded by gneissose feldspathic granite, gneissose biotite granite, pegmatite dikes containing tourmaline, monazite, and cassiterite, and a late sequence of intrusive rocks which includes cassiterite-bearing granite (Raeburn, 1926, p. 12, 17).

Near Bauchi two bodies of monazite-bearing syenite are exposed (Bain, 1926, p. 64).

In southeastern Zaria Province, fine-grained biotite gneiss is intruded by gray porphyritic biotite granite, white feldspathic granite, augite syenite, and scattered tourmaline-bearing pegmatite dikes containing some cassiterite (Raeburn, 1927b, p. 11–12). Basaltic flows overlie these rocks in the southern part of the prov-

TABLE 10.—*Mineralogical composition of concentrates from streams in the Mama area, Nassawara Province, Nigeria*

[Analyst: Raeburn (1926, p. 18). Symbols used: V, very abundant; A, abundant; C, common; S, scarce]

	1	2	3	4	5	6	7	8
Ilmenite	V	V	V	V	V	V	V	V
Rutile	A	C	C	A	C	A	C	V
Garnet	C	A	C	C	S	----	----	S
Spinel	S	S	----	----	----	----	----	
Cassiterite	S	C	S	S	S	S	S	
Topaz	S	C	S	S	----	----	----	
Tourmaline	----	----	S	S	----	----	V	
Zircon	A	----	S	C	S	C	----	C
Monazite	C	A	C	C	C	S	C	S
Epidote	----	----	----	----	S	S	----	
Magnetite	----	----	----	----	V	----	S	S

1. Upper Arum River.
2. Middle Arum River.
3. Lower Arum River.
4. Marhai River.
5. Jinni River.
6. Farin Rua at Kwara Baba.
7. Farin Rua bridge, north.
8. Farin Rua bridge, south.

ince. The granite crops out extensively in the Duchin Wei Hills and is the source of detrital monazite found in the valley of the Rakwa River and in the beds of tributaries to the Rakwa (Raeburn, 1927b, p. 27). Alluvial deposits are, however, sparse. Downstream along the Chawai River below the basalt flows, traces of monazite were found by Raeburn (1927b, p. 37) in meager concentrates.

The Leren Dutse Hills (Lerin Duchi Hills), the Liruein Kano Hills, and the Banke Hills are composed of late granite and rhyolite intrusive into a crystalline complex of garnetiferous biotite gneiss and schist, banded biotite gneiss, and gneissose white feldspathic granite and porphyritic biotite granite (Russ, 1927, p. 51–56). The late granite is medium-grained biotite granite that is generally fine grained and porphyritic at the margins. Monazite is an accessory mineral in the late granite but is absent from the associated rhyolite and quartz porphyry. Allanite is, however, a very common accessory in the rhyolite (Russ, 1927, p. 65). Stream sediments in the valleys of the River Baba and River Sheberu contain cassiterite, columbite, zircon, monazite, magnetite, and anatase(?).

Monazite is a common but not a major constituent of concentrates from streams at Kurwasa and Agwarra in a region underlain by variably metamorphosed argillites intruded by hornblende-biotite granite (Tattam, 1936, p. 7–11). Accompanying minerals are ilmenite, zircon, staurolite, kyanite, magnetite, garnet, rutile, tourmaline, epidote, gold, and cassiterite. Commercial production of the monazite, even as a byproduct of gold mining, seems to be unlikely because the tenor is low.

Monazite was reported at Awuru on the Niger River (Netherlands Engineering Consultants, 1959, p. 294).

There is no record of production of monazite in Nigeria prior to 1952, but some may have been mined in 1951. The United Kingdom Ministry of Supply in 1949 set a guaranteed price to be effective for 10 years for the purchase of monazite-thorite concentrates at Jos or Dukura in the tin fields in Plateau Province, but the prices offered were said to be too low to pay for the recovery of the monazite (Clark and Keiser, 1953, p. 1270–1271). In 1952, possibly as a result of the guaranteed price, 6 short tons of monazite was produced in Nigeria, and beginning in 1956 a small but continuous annual output was achieved, (J. G. Parker, written commun., 1962):

	Short tons
1956	86
1957	104
1958	64
1959	15
1960	13
1961	8

REPUBLIC OF CAMEROON

Monazite is generally present in small amounts in concentrates from stream deposits in the Dikwa Division in the northern part of the Republic of Cameroon (Tattam, 1938, p. 8–9). Common associated heavy minerals are ilmenite, magnetite, rutile, brookite, and zircon. Gold and other possibly economic detrital minerals are not common. Sources of the heavy minerals are gray and pink medium-textured granite and ancient Precambrian crystalline rocks which form the hills in the Dikwa Division. Doubtless some detrital monazite is present in the Chad Group of sedimentary rocks, probably of Tertiary age, which are exposed at lower altitudes in the Chad Basin.

Detrital monazite was reported from other parts of the Republic of Cameroon, particularly along the Nigerian border in the direction of the Oban Hills (Marble, 1949a, p. 37). Monazite was said to occur with wolframite and columbite in stream placers, but localities were not cited (Miller, 1939, p. 10; Wright and others, 1938, p. 68). Monazite is a probable associate of cassiterite in stream placers near Garoua (Garua) and in pegmatite dikes near Tibati. Rutile placers in the Yaoundé River (Yaounde River) and ilmenite-zircon-rutile placers in the Dschang Eseka River are likely to contain some monazite (Miller, 1939, p. 10; Wright and others, 1938, p. 68).

REPUBLIC OF GUINEA

Monazite, zircon, garnet, and corundum have been reported from placers in the vicinity of Beyla (Echo des Mines et de la Metallurgie, 1935).

REPUBLIC OF SENEGAL

Concentrates from weathered garnetiferous biotite-muscovite-microcline pegmatite associated with the Saraya granite massif contain accessory tourmaline, apatite, monazite, and thorite and traces of cassiterite and columbite-tantalite (Soulé de Lafont, 1958, p. 249). The Saraya massif is a syntectonic biotite-muscovite granite intrusive into schist and amphibolite. Although the pegmatites occur throughout the massif, they are most numerous in the central part and along the southwest border.

Sands of the Casamance River (Casamanca River) contain ilmenite, rutile, and zircon, and probably contain monazite. Ilmenite and rutile were produced in the area before World War II, but there is no record of monazite production (Miller, 1939, p. 10; Wright and others, 1938, p. 68).

REPUBLIC OF SOUTH AFRICA

CAPE OF GOOD HOPE PROVINCE

The largest known commercial source of monazite in Africa is a vein on the Steenkampskraal farm about 30 miles north of Vanrhynsdorp (Van Rhyns Dorp, Van Rhynsdorp) (MacConachie, 1957a; 1957b; Kremers, 1958, p. 9). The deposit was discovered in 1949 and has been developed by the Anglo-American Corp. of South Africa, Ltd.; production began in 1953. The output, which was planned to reach 8,000 short tons annually (Engineering and Mining Jour., 1953; Mining Jour., 1953, p. 752) of a monazite product containing 45 percent of RE_2O_3, 6 percent of ThO_2, and a trace of U_3O_8, was to be shipped to the United States and Great Britain. Between 1953 and 1956 the output was said to have been 16,230 short tons of monazite (Pike, 1958). An output of 3,000–4,000 short tons of monazite was estimated for 1956–57 by Lecoq (1957, p. 593), but the U.S. Bureau of Mines reported that the output was about 9,000 short tons per year from 1954 through 1956 (J. G. Parker, written commun., 1962, 1963; H. L. Hunt, written commun., 1963). In accounts of the deposit, Kremers (1958, p. 9), MacConachie (1957a), Davidson (1956a, p. 204–205), and Nininger (1954, p. 100) described a vein of fine-grained monazite, apatite and quartz that occupies a conspicuous shear zone in Precambrian granite gneiss. The shear zone is at least 900 feet long and ranges in width from 1 inch to 6 feet. It terminates as a vein of quartz in the granite. Monazite makes up 60–75 percent of the vein material except along the hanging wall where it makes up only 20 percent. Ore along the hanging wall also contains some secondary copper minerals and hematite. Several similar shear zones nearby contain monazite veins.

A pure sample of fine-grained monazite from the main vein had the following composition (Kremers, 1958, p. 9):

	Percent		*Percent*
RE_2O_3	61.17	ZrO_2	0.01
ThO_2	8.01	CaO	2.40
U_3O_8	.08	MgO	.19
P_2O_5	26.10	MnO	.005
SiO_2	1.00	PbO	.05
Al_2O_3	1.14	BeO	.01
Fe_2O_3	.33	H_2O-	.20

The percentage of thorium oxide is high for monazite in general and is unusually high for hydrothermal-vein monazite. The mineral association and the composition of the monazite at Steenkampskraal closely resemble the metamorphic differentiation assemblages observed in granulites in the southeastern part of the Malagasy Republic, but not enough geologic information had been published about the South African vein by 1960 to permit an appraisal of its origin.

The mine produced monazite through 1958 but was closed in 1959 after producing 2,402 short tons (table 1) (Lewis, 1959, p. 5; J. G. Parker, written commun., 1962; H. L. Hunt, written commun., 1963).

The pegmatite dikes that are a conspicuous feature of Namaqualand in the northwestern part of the Cape of Good Hope Province locally contain minor quantities of monazite (Gevers, 1936, p. 366), but minable deposits have not been discovered (South Africa Geol. Survey, 1940, p. 289). In this area the monazite seems to have formed later than microcline and quartz of the epimagmatic stage. It was apparently introduced as a high-temperature replacement mineral along with black tourmaline, spessartite, beryl, fluorapatite, columbite-tantalite, euxenite, fergusonite, xenotime, polycrase, spodumene, and albite. Wherever the monazite is found, it is associated with zones of alteration around later quartz, but its formation was later than the main albitization and muscovitization of the pegmatite dikes (Gevers, 1936, p. 372–373).

Concentrates from the Molteno sandstone in the vicinity of Molteno contain sparse dark-honey-yellow well-rounded grains of detrital monazite associated with detrital diamond, garnet, rutile, kyanite, epidote, zircon, anatase, and tourmaline (Schwarz, 1917, p. 33).

Detrital monazite occurs with zircon, rutile, garnet, and tourmaline in fluvial sands of the Breede River (Coppenhagen, 1945, p. 153–157).

TRANSVAAL PROVINCE

Several occurrences of accessory monazite in sedimentary, igneous, and metamorphic rocks have been reported from Transvaal Province. The origin of the monazite in the Witwatersrand conglomerates has been the subject of considerable discussion and some dispute, which has brought forth detailed descriptions of the occurrence and form of the grains. A study of the composition of the monazite in the Witwatersrand has yet to be made, but it is obviously pertinent to any discussion on the origin of the mineral. The most useful descriptions of monazite in the conglomerates were made by Mendelssohn and Marland (1933) and Liebenberg (1955, p. 114–115, 159, 219, 248).

Monazite is generally a very scarce mineral in the various auriferous conglomerates of the Witwatersrand system (Liebenberg, 1955, p. 159). It seems to be most abundant in the chloritic and sericitic conglomerate at the Sub Nigel mine, where it is concentrated near the contact between the conglomerate and underlying shale (Mendelssohn and Marland, 1933). Isolated crystals of monazite also occur in shale in the footwall. The monazite is patchily distributed in the conglomerate but in some places forms a large part of the rock. Most of the grains of monazite at the Sub Nigel mine are irregular in shape and have a maximum size of about an eighth of an inch. Some small euhedral crystals are present which have brilliant faces and show no evidence of attrition. Most of the monazite is very fresh and unaltered, but some of it is replaced by sericite and chlorite; some grains of monazite, accompanied by sericite and chlorite, are imbedded in quartz. The monazite at the Sub Nigel mine is radioactive, but the amount of thorium in it has not been determined. Possibly the radioactivity of the monazite may result more from the amount of uranium than from the amount of thorium contained. The specific gravity of the monazite from the Sub Nigel mine is 5.16, a value commonly associated with a content of 1–3 percent of ThO_2.

Mendelssohn and Marland regarded the monazite at Sub Nigel mine to be hydrothermal in origin and to be one of the earliest minerals introduced during the sericitization and chloritization of the conglomerate. Liebenberg also interpreted the monazite to be authigenic at the Sub Nigel mine, but he convincingly ascribed its origin to be more-or-less closed-system reactions at a low grade of regional dynamic metamorphism that modified an originally monazite-bearing suite of placer minerals (Liebenberg, 1955, p. 247).

Knowing the abundance of thorium oxide in this monazite would be helpful, because a low tenor in thorium oxide would tend to be compatible with authigenic origin at low temperature, whereas a high tenor would suggest that the grains were detrital relicts. It is this writer's opinion that the monazite at the Sub Nigel mine is probably authigenic.

Detrital grains of monazite were observed by Liebenberg (1955, p. 159, 248) in conglomerate of the Dominion Reefs in the Witwatersrand. These grains were said to be particularly abundant in a sedimentary layer that is highly enriched in detrital minerals; this layer occurs at the top of the conglomerate. Round and oval gray, yellow-brown, and clove-brown grains predominate, but a few variably rounded prismatic grains are also present. In thin section, some of the round grains were seen to be partly replaced around their margin by chlorite, sericite, and leucoxene. These grains are very small; many are less than 0.01 inch across. Polished sections showed minute inclusions of galena in the monazite, and these inclusions were interpreted by Liebenberg to be of radiogenic origin. Associated with the monazite are sparse grains of detrital garnet, cassiterite, chromite, zircon, and ilmenite.

Monazite is disseminated in the Bushveldt granite east of Vlaklaagte (Vlaaklaagte). Large lumps of monazite intergrown with quartz and fluorite have been found in the area. In the same general area, at localities 60–70 miles northeast of Pretoria, lump monazite occurs with quartz, feldspar, fluorspar, molybdenite, pyrite, and various iron minerals in ill-defined pegmatitic veins in red granite (Kotze, 1915; Wagner, 1918, p. 1520; Johnstone, 1918, p. 375; Ladoo, 1927, p. 171; Hall, 1932, p. 498; South Africa Geol. Survey, 1940, p. 289). According to Kotze, half a dozen or more of these veins are scattered over a distance of 2 miles. The maximum observed width of a vein is 3 feet and the maximum explored depth is 40 feet; lengths are not given. The monazite is reddish brown and contains 3.5–4.0 percent of ThO_2 and 1–2 percent of Ta. Veins on the Houtenbek farm were prospected in 1905 and again in 1915; the dumps were said by Kotze (1915) to have contained material from which about 6 tons of ore containing 40–50 percent of monazite could be hand sorted. Apparently the abundance of thorium oxide in the monazite from the Houtenbek area varies considerably. Hall (1932, p. 498) wrote that clove-brown crystals of monazite as much as 2 inches across from this area were too lean in thorium oxide to be of commercial interest, and the South Africa Geological Survey (1940, p. 289) reported 1–4 percent of ThO_2 in the monazite. This monazite may be the same massive monazite analyzed by E. White and reported by Johnstone (1914, p. 57) to contain 1.5 percent of ThO_2, but neither the geologic source nor site of the sample was given by Johnstone.

Monazite occurs as an accessory mineral in cassiterite-bearing red granite 40 miles northeast of Pretoria at Enkeldoorn (South Africa Geol. Survey, 1940, p. 289, 296). Massive monazite was reported from an unspecified locality in the Transvaal 40 miles from the Pretoria–Lourenço Marques Railroad (Zeitschr. angew. Chemie, 1906, p. 1529). It was said to occur in a vein about 4 feet wide which has been explored to a depth of 30 feet. The vein material reportedly contains 13.5 percent of ThO_2, but the composition of the monazite was not given.

Monazite is a common accessory mineral in the Old Granite in the Zoutpansberg district of the northern Transvaal and in the apatite-rich carbonatite deposits near Bandolierkop (Bandolier Kop) in the same district (Janisch, 1927, p. 112–124; Hall, 1938, p. 313; South Africa Geol. Survey, 1940, p. 289). Mixtures of apatite and barite or of apatite, barite, and feldspar form massive layers and veins in an area of schist and pegmatite south of gneissic granite exposed at Zoutpansberg. In these occurrences the apatite is full of inclusions of long thin yellow prisms of monazite which are oriented parallel to the long axis of the apatite. At one exposure, Janisch noticed a pegmatite dike cutting through apatite in schist. Grains of dark-brownish-red monazite, locally clustered around irregular fragments of apatite, are present in the pegmatite. On one side of the pegmatite, monazite forms a layer 1 inch thick. A wide variety of rocks and minerals that include schist, pegmatite, apatite, and orthoclase are present and are commonly monazite bearing. Two analyses of monazite from Bandolierkop showed that it had little thorium oxide:

[Analyst: H. G. Weall, South African Govt. Lab. (in Janisch, 1927, p. 127).]

	Percent	
	A	*B*
CeO_2	35.79	29.10
La_2O_3, Y_2O_3	32.17	33.60
ThO_2	2.07	2.40
P_2O_5	28.72	27.70
SiO_2	1.84	1.80
Al_2O_3	------	.60
Fe_2O_3	------	[1] 4.00
CaO	------	.40
Total	100.59	99.60

[1] Secondary coating.

A. Very fine grained monazite included in apatite from Bandolierkop.
B. Monazite from Bandolierkop.

Similar monazite reported to contain 1.5–2.5 percent of ThO_2 accompanies opaline silica in alteration zones in granite west of Bandolierkop (South Africa Geol. Survey, 1940, p. 289).

The possibility that the monazite-bearing apatite-barite and apatite-orthoclase veins at Bandolierkop have the same origin as carbonatite deposits was not mentioned by Janisch. The apatite-bearing carbonatite at Loolekop in the eastern Transvaal would seem to suggest this possibility (Russell and others, 1954, p. 197; Smith, 1956, p. 198). No monazite has been reported from the Loolekop carbonatite, but this carbonatite contains several unusual minerals among which are uranoan thorianite and baddeleyite; this occurrence is the first reported for uranoan thorianite and baddeleyite in South Africa.

A somewhat similar monazite from an unspecified locality in the Transvaal was analyzed in 1905, and the results of the analysis were given in 1927. This analysis and a near duplicate were published in 1922 by Carl Hintze, who mentioned no location other than the Transvaal. The monazite had a specific gravity of 4.93, and the composition was as follows:

[Analysts: *A*, L. Andersen-Aars in 1905 (in Janisch, 1927, p. 127, and Hintze, 1922, p. 370); *B*, Hintze (1922, p. 370).]

	Percent	
	A	*B*
Ce_2O_3	34.58	34.50
La_2O_3	11.25	11.77
Nd_2O_3, Pr_2O_3	16.00	15.60
Y_2O_3	2.14	1.99
ThO_2	3.51	3.48
P_2O_5	27.38	27.15
SiO_2	1.52	1.44
Al_2O_3	.86	.77
Fe_2O_3	.44	.40
Ta_2O_5	.15	.21
SnO_2	.29	.33
CaO	.31	.48
Loss on ignition	2.21	2.18
Total	100.64	100.30

The possible occurrence of monazite in granite in the Forbes Reef area in the Barberton gold mining district in the eastern Transvaal and the Swaziland Protectorate was mentioned about 48 years ago by Hall (1918, p. 238). More recently monazite was said to have been found in the Barberton district, but the nature of the occurrence was not described (South Africa Geol. Survey, 1940, p. 289). Possibly the cited occurrence refers to the small subhedral clove-brown grains of detrital monazite found along the banks of the Sandspruit about 8 miles south of Steynsdorp near Oshoek adjacent to the border with the Swaziland Protectorate (Hall, 1918, p. 309). This monazite may be from gray granite in the area. Disseminated and massive monazite is known to occur in dikes of garnetiferous pegmatite in the same area (South Africa Geol. Survey, 1940, p. 289). The pegmatite also contains cassiterite, aeschynite, and fergusonite. Some time prior to 1918 about 3.5 tons of detrital coarse brown monazite was recovered in the Oshoek tin fields between Forbes Reef and the Komati Ferry (Hall, 1918, p. 316), but possibly most of this output came from placers in the Swaziland Protectorate.

Sandstone in the Karroo system in Transvaal Province is fairly rich in detrital heavy minerals but contains only small amounts of monazite (Koen, 1955, p. 284, 319). Grains of monazite are yellow or brown, well rounded, tabular, or irregular and are free from inclusions; locally they are coated by a felted black or brown alteration(?) material. In most of the monazite-bearing concentrates, the abundant heavy minerals are titanite, rutile, and tourmaline; monazite and epidote are sparse, and staurolite is very uncommon. Probably the source of the monazite is ancient granite and gneiss in northern and eastern Transvaal. In the samples of sandstone studied, monazite seems to increase in abundance toward the east.

The northwesternmost area of Karroo sandstones studied was the Waterberg coal field in northwestern Transvaal (Koen, 1955, p. 357–360). Of 133 concentrates, 21 are monazite bearing, but even in these concentrates the monazite is very sparse. Of the 21 monazite-bearing concentrates, 10 are from sandstone of the Lower Ecca stage which overlies tillite, possibly of the Dwyka series, at the base of the Karroo system. Above the Middle Ecca stage the samples from the Karroo system at the Waterberg coal field are devoid of monazite. Thus, about 1,800 feet of sedimentary rocks in the upper part of the section lacks monazite and about 810 feet of rocks in the lower part of the section contains monazite.

Of 34 samples taken from two drill holes in the Springbokvlakte (Springbok Flats) north of Pretoria, 3 concentrates contain monazite. In each of the three concentrates, the monazite is very scarce. The Lower Ecca stage of the Karroo system is missing in the area where the holes were sunk, and the monazite was found in the middle and upper part of the system. One monazite-bearing sample is from the Middle Ecca stage, and the two others are from the Cave Sandstone stage near the top of the Karroo system (Koen, 1955, p. 361).

At the Witbank coal field 34 samples from three drill holes in rocks of the Middle Ecca stage were examined, and 9 samples were found to contain scarce monazite (Koen, 1955, p. 301).

A deep hole near Harrismith in the Kestell area was the source of 45 samples from the upper and middle parts of the Karroo system. Monazite is in 2 out of 4 samples from the Cave Sandstone, 9 out of 30 samples from rocks of the Lower Beaufort stage, and 6 out of 11 samples from the Middle Ecca stage (Koen, 1955, p. 363–364).

NATAL

Detrital monazite is found in the beach sands at Durban (Partridge, 1939) and in beach and dune sands elsewhere along the Victoria County coast of Natal (Kent, 1939, p. 19–21, 31–36). The proportion of heavy minerals in the beach sand at Durban was said to range from 5 to 90 percent of the raw sand. Ilmenite is by far the most common of the heavy minerals. The average composition of three heavy concentrates from Durban beach sand was as follows (Partridge, 1939):

	Percent		Percent
Ilmenite	83.3	Leucoxene	0.5
Zircon	7.5	Monazite	.3
Garnet	3.2	Tourmaline	.2
Amphibole and pyroxene	3.1	Glauconite	.05
Magnetite	2.1	Rutile	.1
		Epidote	Trace

The composition of monazite-bearing concentrates from various sources in Natal is shown in table 11; the total abundance of heavy minerals is low.

TABLE 11.—*Mineralogical composition, in weight percent, of monazite-bearing concentrates from sands in Natal, Republic of South Africa*

[Analyst: Kent (1939, p. 31–36). Symbol used: ------, not reported]

	1	2	3	4	5
Heavy minerals	------	1.36	1.9	6.0	5.6
Magnetite	9	7	10	3	6
Ilmenite	7	74	78	77	82
Leucoxene	------	1	2	5	------
Rutile	Trace	4	3	3	3
Garnet	3	------	------	------	2
Zircon	32	13	9	11	7
Epidote	2	------	Trace	------	Trace
Sphene	10	------	------	------	------
Apatite	5	Trace	------	------	------
Monazite	1	0.5	Trace	Trace	Trace
Kyanite	------	------	Trace	------	------
Biotite	------	------	Trace	Trace	------
Hornblende	30	------	Trace	------	Trace
Augite	------	------	Trace	Trace	Trace
Tourmaline	------	1	Trace	1	Trace

1. Stream sand derived from gneiss, schist, and granite in Victoria County.
2. Eolian red sand at Port Edward on north bank of Mthamvuna River (Umtamvuna River).
3. Eolian red sand from top of Berea Range, Durban.
4. Eolian brown sand from vicinity of Umdloti Beach (Umhloti Beach), Victoria County.
5. Beach sand at high-tide level near mouth of Tongaat River, Victoria County.

The monazite-bearing eolian sands along the coast of Natal are probably Pleistocene to Recent in age. They occur as bands of brightly colored white, gray, dark-brown, and deep-red dunes as much as 400 feet high which partly conceal older raised beaches and river terraces. Deposits of windblown sand extend inland from 1 to 3 miles (Kent, 1939, p. 19–21).

REPUBLIC OF THE CONGO

(Léopoldville)

The most frequently described occurrences of monazite are at Shinkolobwe and Kasolo in Katange Province. Monazite forms veins and masses of small honey-yellow crystals in and associated with uranium ore and is found as euhedral crystals in talc schist, micaceous dolomite, and sklodowskite-bearing magnesite-rich schist (Schoep, 1930, p. 41; Thoreau and de Terdonck, 1933, p. 31–38; Thoreau and others, 1936, p. 1111; Derricks and Vaes, 1956, p. 112). The origin of the deposits was ascribed by Derricks and Vaes (1956, p. 125–128) to pneumatolitic and hydrothermal processes related to a deep-seated and unexposed intrusive. Several outcrops of trachyte east of the mine were cited to substantiate the inference of magmatic origin. The monazite veins and uraninite ore are in folded and faulted Precambrian metasedimentary rock that originally consisted of argillaceous dolomite, argillite, dolomite, and sandstone. Slight regional metamorphism and pervasive magnesia metasomatism of the sedimentary rocks prior to the deposition of the ore produced crystalloblastic magnesia-rich dolomite, argillaceous talcose schist that has magnesite crystalloblasts, dolomitic chlorite schist, and dolomitic quartzite. Introduction of the monazite veins was accompanied by local chloritization of the rocks.

Monazite from Shinkolowbe and Kasolo was reported to be nonradioactive (Schoep, 1930, p. 42; Schoep and others, 1932, p. 30), and monazite from eluvial gold placers that overlap the uranium deposits in the district was shown to contain only 0.2 percent of ThO_2 (Thoreau and others, 1936, p. 1115–1118; Lane, 1938a, p. 48; Palache and others, 1951, p. 694):

[Analyst: Tougarinoff, Anal. Chemistry Lab., Univ. Louvain]

	Percent
CeO_2	32.29
La, Pr, Nd, and other members of the lanthanum series	41.63
Y_2O_3 (group)	Trace
ThO_2	.2
P_2O_5	24.90
SiO_2	.95
Fe_2O_3	Trace
CaO	.37
MgO	Trace
Total	100.34

The abundance of helium in monazite from 'nZokwé and Elila Aval was shown by Itterbeek and Van Paemel (1950, p. 8) to be in the range of 0.47 to 0.74 cubic centimeter per gram of monazite, a low value compared to the amount of helium found in monazite and thorianite from other localities.

Placer monazite has been found in the concentrates from gold- or cassiterite-bearing streams in many parts of the Republic of the Congo including the gold-bearing region in the northeastern part (Corin, 1931, p. 151). Monazite has been particularly mentioned in deposits along the Kasangashi (Kalangashi) River, Lulua River region including the Nange-Nange and Katepiti Rivers and in placers in the Maniéma District where it is associated with gold, diamond, sapphire, corundum, cassiterite, and wolframite (Buttgenbach, 1947, p. 410; Hintze, 1922, p. 344; Rouseaux, 1939, p. 1477; Davidson, 1953, p. 75).

Many placer mining concessions in the Republic have been reported to be possibly monazite-bearing, among which are those on the Uele, Gurba, Bomokandi, Tele, Ituri, Poko, Mompela, Loko, and Sili Rivers (Congo Belge Bull. Officiel, 1926a, p. 489–493), but it is not certain that monazite is present in any of them. Monazite was found in the Lindi River basin in a tributary known as the Tayna (Tanya) River (Congo Belge Bull. Officiel, 1926b, p. 784). Branches of the Tayna River called the Mohanga and the Lutunguru Rivers were also said to be monazite bearing (Congo Belge Bull. Officiel, 1926b, p. 788, 790).

The Republic of the Congo produced monazite from 1951 to 1956, but the sources of the monazite have not been described (Franklin and Eigo, 1955, p. 81; J. G. Parker, written commun., 1962):

	Short tons
1951	41
1952	15
1953	12
1954	4
1955	5
1956	1

RUANDA-URUNDI

Monazite was reported to occur as an accessory mineral in granite in western Ruanda and to form placers in the valleys in the basin of the Rukarara River (Fontainas and Ansotte, 1932, p. 25). It was also said to be found at the confluence of the Rukarara and Binana Rivers and of the Ruyobora and Agafuguto Rivers, but the extent of the occurrences was not given (Congo Belge Bull. Officiel, 1933, p. 517, 524, 527; Miller, 1939, p. 9).

Monazite occurs in granitic rocks at Runyinya (Runinya), 15 miles southeast of Astrida (Holmes and Cahen, 1955, p. 25).

SIERRA LEONE

Some weathered granitic rocks in Sierra Leone were said to contain as much as 20 pounds of monazite per ton of residuum in volumes large enough for mining, but specific localities have not been described. Zones of migmatite in the interior of the country contain monazite which has 10–12.6 percent of ThO_2 (Davidson, 1956a, p. 202).

Pink and white monazite is in alluvium thought to be derived from vertically dipping elliptic masses of synorogenic granite in amphibolite near Bumbuna (Dixey, 1954, p. 74). Alluvial and eluvial monazite in the Sula Mountains was said to be derived from synorogenic coarse-grained granite and migmatites (Holmes and Cahen, 1955, p. 29–30).

Concentrates from streams crossing a gray medium-grained porphyritic biotite granite between Saionya and Kamabai and between Kamalu (Kamalo) and Kamabai locally contain monazite associated with magnetite, zircon, rutile, and epidote (Junner, 1929, p. 9–10). Similarly, streams crossing a medium-grained biotite granite in the vicinity of Manowa (Manoa) and between Kailahun and Pendembu contain some monazite associated with dominant zircon, magnetite, and ilmenite. Locally rutile, garnet, epidote, corundum and sporadic flakes of gold are present in the concentrates (Junner, 1929, p. 11). Streams in areas underlain by foliated biotite granite in the drainage basin of the Mano River and in the southeastern part of the Kenema District contain detrital monazite associated with purple and lilac zircon, magnetite, ilmenite, garnet, epidote, corundum, and a small amount of gold (Junner, 1929, p. 11).

Small amounts of monazite are found in concentrates from streams that drain the gneisses and crystalline schists of the coastal plain at Gbangbatok (Gbangbatuk) and Gbangbaia in the Gbangbama District of the Southern Province of Sierra Leone near the Liberian border (Junner, 1929, p. 5). The principal minerals in the concentrates are zircon, ilmenite, garnet, and corundum; small amounts of tourmaline, rutile, kyanite, and gold are present. Similar concentrates were found in the Jong River between Matru and Wobange.

Concentrates taken from the Pampana River at several localities between Mamaya and Mamansu contain some monazite, rutile, and corundum but consist mainly of magnetite, ilmenite, garnet, and zircon (Junner, 1929, p. 10; Davidson, 1953, p. 75). Small amounts of tourmaline, anthophyllite, epidote, sphene, actinolite, cassiterite, and gold are present.

Alluvial deposits of monazite, rutile, ilmenite, and zircon were reported by Junner (1952) to be especially common near the coast of Sierra Leone. They were said to have commercial possibilities but had not been adequately explored by 1952.

Sandbars and beaches along the Atlantic coast of Sierra Leone were being prospected in 1955 for titanium placers. Davidson (1956c) predicted that these placers were a likely source for thorium-rich monazite.

SOMALI REPUBLIC

The first mention of monazite in the Somali Republic is Artini's account of its occurrence as a minor accessory mineral in the alluvium of the Giuba (Juba) River and in sandstone in the interior of the Republic at Lugh Ferrandi (Lugh), Monte Curetca (Curetka), and Scidle (Artini, 1915; Mining Jour., 1915; Metallurgie und Erz, 1916; Hintze, 1922, p. 344). Grains of monazite from the Giuba are ordinarily no larger than 0.004 inch and are yellow. Monazite is very scarce in the river sands and amounts to less than 0.1 percent of the concentrate. The monazite is accompanied by augite, almandine, zircon, scarce epidote, green spinel, pyroxene, hornblende, tourmaline, kyanite, staurolite, sphene, and apatite. The small amount of monazite in the sandstone in the interior of the Somali Republic was thought by Artini to be the origin of the monazite in the Giuba River.

Natural black sands are concentrated on the seaward side of a belt of coastal dunes near the mouth of the Giuba River (Mining Jour., 1915; Holmes, R. J., 1954, p. 66). The concentrates consist principally of ilmenite but also contain about 0.06 percent of monazite, an amount too small to be economically recoverable.

The source of the small amount of monazite in the sands of the Giuba River was attributed by Ettore Artini to equally sparse occurrences of monazite in sandstone in the interior of the Somali Republic (Artini, 1915, p. 558). Among the possible sources cited by R. J. Holmes (1954, p. 68) are rocks in the crystalline complex of the Bur region, Jurassic sandstone in the upper reaches of the Giuba River above Bardera, and Upper Triassic sandstone in the river valley in the Dola (Dolo) region.

Primary monazite occurs in samarskite-bearing pegmatite dikes in crystalline rocks in the southern part of the Berbera District of the Somali Republic. Dikes at a locality about 6 miles northeast of Laferug and near Daarbuduq contain monazite which was reported to have 10 percent ThO_2 (Pallister, 1958, p. 162).

SOUTH-WEST AFRICA

Monazite has been frequently mentioned as a sporadically occurring accessory mineral in pegmatite dikes exposed over a very large area near the Erongo Mountains; it is commonly associated with cassiterite, wolframite, tantalite, and a variety of other minerals (South African Mining Jour., 1911; Rimann, 1913, p. 67; Gevers and Frommurze, 1930, p. 139; Haughton and others, 1939, p. 25; Marble, 1949a, p. 37). The pegmatite dikes occur in three well-defined zones named by Gevers and Frommurze (1930, p. 111–112) the Northern belt, which is between Uis and Brandberg, the Great Central belt, which extends from the Omaruru River west of Neineis to the Kompaneno Mountains, and the Great Southern belt, which extends from near Ebony to the southwest corner of the Erongo Mountains. Various subsidiary branches of the Great Southern belt are known in the Erongo Mountains.

The oldest rocks are mica schists, amphibolites, and quartzites; they are complexly folded along northeast-trending axes (Gevers and Frommurze, 1930, p. 113–116). Concordantly intruded into the metasedimentary rocks are gneissic granite, granite, aplite, and pegmatite. These granitic rocks commonly form broad domes or occupy the crests and troughs of folds. They were probably introduced during the main deformation of the metasedimentary rocks, the pegmatite dikes being the culmination of the intrusive episode. A later period of folding exposed the plutonic rocks to erosion; on the erosional surface were deposited the unconformably overlying sediments that formed the Phyllite formation and the younger sedimentary rocks and in addition the volcanic flows.

The pegmatite dikes in the three belts are classed by Gevers and Frommurze (1930, p. 113) into two groups: the tourmaline pegmatites and the tin-bearing pegmatites. The pegmatites of both groups consist principally of orthoclase, microcline, albite, perthite, and quartz. Black tourmaline is the characteristic accessory mineral of the tourmaline pegmatites. The tourmaline pegmatites are most common in and adjacent to the parent granitic rocks; monazite is not mentioned as an accessory mineral. Cassiterite is the characteristic accessory mineral of the tin-bearing pegmatites, but these pegmatites also contain lithium tourmaline, muscovite, lepidolite, cookeite, triplite, lazulite, almandine, apatite, topaz, fluorite, beryl, tantalite, wolframite, monazite, columbite, molybdenite, bismuthinite, arsenopyrite, chalcopyrite, and bornite. Most of these minerals occur sporadically. After the pegmatite dikes formed, they were folded and some were converted to sillimanite-albite-muscovite gneisses.

The tin-bearing pegmatites in the Omaruru area, including part of the Great Central belt, were described in detail by Haughton and others, (1939, p. 25) who reported that monazite is locally present. They also recognized a much later tin and tungsten mineralization than the one associated with the tin pegmatites. It affected the unconformably overlying sedimentary rocks and volcanic flows and is especially notable at a conical hill known as Kranzberg (Haughton and others, 1939, p. 83–99). Mineralization at Kranzberg was thought not to include a true pegmatite stage but to involve an early hydrothermal stage related to late intrusives. During the hydrothermal activity, fracture zones in ancient schist and granite at Kranzberg were thoroughly altered; quartz-topaz rock formed, and tourmaline, apatite, muscovite, wolframite, fluorite, feldspar, scheelite, and small amounts of tungstite, monazite, zircon, bismuth, pyrite, and bismite were deposited. The alteration extended into the boulder beds, slate, and amygdaloidal lavas that form the crest of Kranzberg and that unconformably overlie the old schist and gneiss.

Monazite occurs in pegmatite dikes exposed in tributaries to the Visrivier (Fish River) and is associated with tantalite in undescribed deposits in the southern part of South-West Africa adjacent to the north bank of the Orange River (Imperial Inst. [London] 1915, p. 251; Mining World 1957b).

SWAZILAND PROTECTORATE

Monazite was first observed in the Swaziland Protectorate in 1896 when it was found in alluvial tin concentrates from Mbabane (M'Babane, Embabaan, Em'babane) where it occurs as heavy clove-brown crystals (Prior, 1899, p. 96; Hahn, 1903, p. 43; 1912; South African Mining Jour., 1912; Chem. Metall. and Mining Soc. of South Africa Jour., 1913; Rogers, 1916, p. 7; Bond, 1929, p. 659; 1930, p. 342). Associated with the monazite and cassiterite are aeschynite, fergusonite, euxenite, scheelite, corundum, magnetite, ilmenite, and garnet (South Africa Geol. Survey, 1940, p. 300; Hintze, 1922, p. 345). Analysis of the monazite by R. Hallack of the Department of Chemistry of the South African College disclosed 6.66 percent of ThO_2 (Chem. Metall. and Mining Soc. of South Africa Jour., 1913). Johnstone (1918, p. 375) reported 6.5–7.0 percent of ThO_2 in the monazite. An unusually low, probably incorrect determination of the specific gravity of monazite from Mbabane placed it at 4.62 (Prior, 1899, p. 96).

The source of the monazite at Mbabane was said to be cassiterite-bearing pegmatite dikes near a contact between granite and metamorphosed volcanic rocks (Merensky, 1908, p. 31; Bond, 1929, p. 659; Hunter, 1957, p. 102).

The alluvial monazite deposits at Mbabane are regarded as of no economic importance, but a few tons of monazite were recovered in the early 1900's from alluvium in the bed of the Komati River north of Forbes Reef, Swaziland Protectorate (Bond, 1930, p. 342). This output is probably the same as that attributed to the Barberton district, Republic of South Africa.

Monazite is a minor accessory mineral in cassiterite-bearing concentrates from alluvial deposits in the Mhlatuzane (Mhlatusane) River about 1.5 miles northwest of Kubuta in the southern part of the Swaziland Protectorate (Hamilton, 1939, p. 77). The area is underlain by banded coarse-grained sphene-bearing biotite-hornblende granite and associated pegmatites. In approximate order of abundance the minerals in concentrates from the placers are magnetite, ilmenite, hematite, cassiterite, topaz, zircon, monazite, euxenite, and apatite. Commercial possibilities of the placers as a source of monazite, if any, have not been described.

Quartzite of the Mozaan series in the Swaziland Protectorate was said to contain detrital monazite, thorite, and zircon locally (Davidson, 1955, p. 70).

TANGANYIKA

Complex granitic pegmatite dikes in Tanganyika are monazite-bearing in at least six localities (McKie, 1957, p. 168–169). These dikes include the discordant well-zoned pegmatites in garnetiferous biotite gneiss, biotite gneiss, hornblende gneiss, graphitic gneiss, and crystalline limestone in the Uluguru Mountains; the discordant zoned pegmatites in feldspathic gneiss and biotite gneiss in the Ukaguru area; the unzoned scattered pegmatites in biotite gneiss and semipelitic gneiss of the Rubeho Mountains; pegmatites in the Bundali Hills; pegmatites in the Mikese area of the Morogoro District; and pegmatites east of Songea. The pegmatite dikes consist pricipally of quartz, feldspars, and muscovite and commonly include some of the following rarer minerals: Lepidolite, spodumene, tourmaline, topaz, cassiterite, beryl, tantalite-columbite, zircon, uraninite, thorite, apatite, monazite, allanite, sphene, kyanite, garnet, samarskite, xenotime (McKie, 1957, p. 168–169; Sampson, 1957, p. 144). Monazite, which is generally sparse, seems to have formed relatively early in the paragenetic sequence. The monazite is locally replaced by allanite. Although the pegmatites are widely mined for muscovite and the Uluguru pegmatite dikes have furnished many specimens of uraninite for museums, there is no economic occurrence of monazite in these pegmatite dikes.

Monazite and quartz occur as fine-grained aggregates forming pseudomorphs after a coarse-grained hexagonal mineral in a carbonatite body at Wigu Hill on the Mgeta River near Kisaki in the Morogoro District south of the Uluguru Mountains (Bisset, 1956, p. 6–7; South African Mining and Eng. Jour., 1956b). Size of the occurrence was not reported.

Two widely separated occurrences of monazite in crystalline rocks were described by Stockley (1947, p. 406). At one place monazite is in Precambrian metasedimentary rocks of the Muva-Ankolean system about 30 miles southwest of Masasi. At the other locality monazite occurs in pegmatite in rocks of the Muva-Ankolean system about 16 miles southwest of Tukuyu.

Some of the sedimentary rocks of Tertiary age along the coast and in large river valleys of Tanganyika contain monazite, diamonds, and gold. Minable monazite placers have yet to be discovered in the Tertiary sedimentary rocks or in sediments eroded from them and deposited in streams or at the beach (Stockley, 1947, p. 379; Davidson, 1956a, p. 202).

Sparse monazite was dubiously identified among the detrital minerals in a few concentrates from Uruwira mineral field on the borders of Kigoma and Tabora Districts (Stockley, 1939, p. 11–12). The concentrates consisted of magnetite, ilmenite, zircon, garnet, epidote, tourmaline, hornblende, rutile, andalusite, hypersthene, monazite, apatite, kyanite, and gold. Monazite was dubiously present in concentrates from three localities on the Mpanda River, from eluvial sand southeast of Kabungu Hill, and from sandstone and quartzite of Paleozoic age exposed at Uruwira.

Monazite-bearing sand has been found in the southeastern Mkata (Mkatta) Plains (Teale, 1936, p. 43; Miller, 1939, p. 9), and monazite has been listed for several unspecified localities in Tanganyika (Imperial Inst. [London] 1914b, p. 598; Waeser, 1939, p. 131; Williams and Skerl, 1940, p. 25).

A far more general distribution of monazite in Tanganyika than these few occurrences indicate is suggested by the presence of monazite in the coastal Tertiary sediments. Monazite will probably be found in the alluvium of streams draining the greatly metamorphosed rocks of the Basement system and migmatites and gneissose granites formed from them, which together underlie 70 percent of the country (Stockley, 1947, p. 378–381). Lacustrine sediments, fan detritus, and surficial mantle derived from the migmatites and old gneisses likewise will probably prove to be monazite bearing.

No production of monazite has been reported from Tanganyika.

UGANDA PROTECTORATE

Monazite is widely distributed in the river sands of Uganda Protectorate, particularly in gold-placer districts underlain by granite or granite in contact with schists of low metamorphic facies (Imperial Inst. [London], 1922; Marble, 1949b, p. 91). Some of the monazite in the gold placers is low in thorium oxide (Marble, 1948, p. 12). Monazite, in uneconomic quantities, was also said to be associated with wolframite, cassiterite, and tantalite in altered muscovite, sericite, and chlorite schists (Fontainas and Ansotte, 1932, p. 25; Brown, 1937, p. 145).

Monazite occurs with sparse gold in stream placers northwest of Mbabara, particularly in the Bwizibwera and Maseruka areas (Wayland, 1933, p. 21–22; Imperial Inst. [London], 1933a, p. 269; Davies and Bisset, 1947, p. 172). The region is underlain by granites, generally biotitic and gneissic and locally porphyritic or muscovitic; the granite intrudes quartzite, conglomerate, and sericitic quartzite probably part of the Karagwe-Ankolean system, and mica schist of unknown age. Monazite is particularly abundant in concentrates containing scant gold from the swamps just west of Maseruka, but the concentrates are small (Wayland, 1933, p. 23). Monazite is also abundant, but gold is scant, in tributaries to the Rusangwe River in the vicinity of Mbuga. The streams flow over decomposed granite in valleys that are only about 150 feet wide at the maximum. Most of the monazite is in a layer of gravel 1–2 feet thick on top of the weathered rock. Headwater branches of the Kitomi River to the east and north of Marangara are monazite-bearing where they rest on quartzite bedrock, but the valleys are small and the monazite is not abundant (Wayland, 1933, p. 26). Other monazite-bearing streams in this area are the Kyamutanga, Bwizibwera, Luhagura, Kinyamatehe, Kanyambarara, Nkurungu, and the Kitagwenda Rivers. For the most part they flow over granite, and none seems to have minable monazite placers (Wayland, 1933, p. 28–29, 41).

The Buhwezu area in Ankole District has detrital monazite in stream placers where gold, cassiterite, and wolframite have also been found (Uganda Protectorate Geol. Survey, 1949, p. 23–24). Locally as much as 90 percent of the concentrate was monazite (Davies, 1942, p. 12). The area is underlain by sedimentary rocks of the Karagwe-Ankolean system which lie unconformably on phyllite, mica schist, and quartzite of the Toro system intruded by granite masses of post Karagwe-Ankolean age (Uganda Protectorate Geol. Survey, 1949, p. 23). Alluvial monazite has been found to come from the granite and quartz veins. Most of the gold placers are worked out, and the monazite is not sufficiently abundant for mining nor does it have a tenor in thorium oxide within industrial specifications. An analysis of monazite from the Buhwezu gold placers made by the Imperial Institute of London showed only the following amount of thorium oxide (Davies, 1942, p. 12):

	Percent
Ce_2O_3 (group)	64.90
Y_2O_3 (group)	4.70
ThO_2	.47
P_2O_5	29.55
Other oxides (not shown)	.09
Total	99.71

Other concentrations of detrital monazite are known in the same general region. Localities mentioned in the literature include the Kabale River near Nyakishenyi and downstream in Kigezi District and at Igara (Imperial Inst. [London], 1935a, p. 494; Davies, 1942, p. 12; Combe and Simmons, 1933, p. 129–136).

Monazite has not been produced in the Uganda Protectorate.

UNITED ARAB REPUBLIC

Placers containing ilmenite, magnetite, monazite, and other heavy minerals were opened about 1936 in the Nile River Delta along the Mediterranean coast of the United Arab Republic between Rosetta and Damietta. The placers have been exploited principally for ilmenite and magnetite with intermittent recovery of zircon and monazite (Gindy, 1961, p. 437; Hilmy, 1951, p. 118; Shukri, 1949, p. 522). The production of 1.1 short tons of monazite was recorded for 1936 (Sanderson, 1943, p. 71), and small annual outputs of monazite are known for most of the period 1948–59 (J. G. Parker, written commun., 1962):

	Short tons		Short tons
1948	7	1954	9
1949	3	1955	1
1950	80	1956	7
1951	1	1957	Not available
1952	7	1958	Not available
1953	7	1959	165

Output of black sand was reported (Baker and others, 1960, p. 36) to have been as follows:

	Short tons
1955	7,909
1956	8,318
1957	7,667
1958	7,272

The percentage of monazite in the black sand is known to have been small, but apparently only about 10 percent of the available monazite in the black sand was being recovered. A typical concentrate was described by Nakhla (1958, p. 8) as follows:

	Percent		*Percent*
Ilmenite	50.67	Quartz	7.26
Magnetite	15.16	Hornblende	2.38
Zircon	7.29	Calcite	1.12
Garnet	1.83	Sphene	.20
Monazite	1.06	Other minerals	1.21
Rutile	1.04		
Augite	10.78	Total	100.00

A separation plant in Alexandria, operated prior to September 1957 by the Anglo-Egyptian Mining Co. and thereafter by the Government-controlled Egyptian Black Sands Co., was being redesigned in 1959 to process 30,000 tons of black sand per year from Rosetta and to recover 70 percent of the monazite in a feed of the following composition (Baker and others, 1960, p. 37):

	Percent
Ilmenite	55.0
Magnetite	18.0
Zircon	8.0
Rutile	1.5
Monazite	.5
Garnet	4.0
Other minerals	13.0
Total	100.0

According to Davidson (1950) and Nakhla (1958, p. 1–8), the black-sand deposits occur along the northern part of the Nile River Delta and are concentrated into workable deposits at the Rosetta Mouth. The greatest single deposit is a flat spit about 1,300 feet wide extending about 2.5 miles southward between the Rosetta Mouth and the Mediterranean. A similar spit on the west side of the Damietta Mouth of the Nile also contains black sand, but not in as great abundance as at Rosetta. Inland dune deposits are present at Rosetta but not at Damietta. At both localities the abundances of the heavy minerals in the natural sand is variable, but in the richer streaks they constitute 20–90 percent of the sand. Davidson (1950, p. 534) noted that offshore between the Rosetta and Damietta Mouths, the bottom sand has been described as black and heavy, and Nakhla (1958, p. 1–8) mentioned that fossil placers, though not known, probably occur in buried beaches of the Nile.

At the Rosetta Mouth, wave action makes a preliminary concentration of the heavy minerals on the beaches. This concentrate is further enriched by the action of northwesterly winds; these winds blow the beach sands toward the Nile where the heavier minerals are deposited along the spit and blow the quartz into the river or onto deltaic flats beyond. From Rosetta to Damietta the outcropping black sands are scattered and in general occur as narrow strips adjacent to the sea. Particularly favorable localities are beaches facing toward the west or northwest, where the greatest concentration of heavy minerals is toward the north end of the beach which is in the direction of the prevailing wind (Davidson, 1950, p. 533; Nakhla, 1958, p. 2).

Estimates of the reserves of total heavy minerals in the delta are very large. Figures as great as several hundred million tons have been cited (Baker and others, 1960, p. 36), but even this estimate is probably low. Many of the components of the heavy sands are not commercial minerals, however; and some of the minerals, notably the ilmenite, are below world-market specifications for composition.

Pure concentrates of monazite from Rosetta are buff brownish orange and fluoresce a deep vermillion under ultraviolet light (Gindy, 1961, p. 437). About 85 percent by weight of the detrital monazite occurs as round to oval grains 73–135 microns in size; some individual grains are subhedral. A monazite separate consisting of about 98 percent monazite was shown by chemical analysis to contain 5.80 percent of ThO_2 and 0.44 percent of U_3O_8 (Gindy, 1961, p. 437).

Black sands from the Rosetta Mouth differ from typical suites of heavy minerals from the Nile River in that they are poor in both pyroxene and amphibole and contain more augite than hornblende. These differences were attributed by Shukri (1949, p. 522) to the sorting action on the beach. The full suite of heavy minerals observed in sediments from the Nile River is given below, in approximate order of decreasing abundance (Shukri, 1949, p. 515; Gutzeit and Kovaliv, 1939, p. 264; Hilmy, 1951, p. 117–118):

Magnetite	Epidote	Monazite
Ilmenite	Garnet	Kyanite
Hornblende	Tourmaline	Staurolite
Augite	Biotite	Apatite
Diopside	Zircon	Spinel
Aegirite	Rutile	Olivine
Enstatite	Brookite	Zoisite

In addition, in a few places the heavy mineral suites from the Nile contain hematite, limonite, muscovite, hypersthene, tremolite, glaucophane, actinolite, chlorite, clinozoisite, sphene, andalusite, sillimanite, topaz, and fluorite. The iron minerals, hornblende, and augite, form 90 percent of the suite. It has been estimated that 140,000 tons of heavy minerals is transported annually by the river to its mouths (Davidson, 1950, p. 533). About 40,000 tons of heavy sand was said to be deposited each year at the Rosetta Mouth (Baker and others, 1960, p. 36). Inasmuch as a large part of these heavy minerals are originally derived from the Abyssinian Plateau (Hilmy, 1951,

p. 117–120), the Aswan High Dam may ultimately impede this transport.

ASIA

The monazite deposits of Asia include both the world's largest known reserves, which are the beach placers that extend along the Malabar and Coromandel coasts of India, and the world's most thorium-rich commercially exploited monazite deposits, which are placers in Ceylon. The resources of monazite in the stream and beach placers of southeast Asia and Korea seem to be immense, but in most areas the mining of the deposits will depend on the successful beneficiation of multimineral concentrates in which monazite is associated with ilmenite, rutile, cassiterite, wolframite, and gold. The vast extent of Asia, reaching from the frontiers of India, Burma, and Korea to the Arctic Ocean, is certain to contain areas having monazite resources as abundant as those of southeastern parts of the continent.

BURMA

Monazite has been found with cassiterite and wolframite in eluvial and alluvial placers in Burma, but it was not saved at the mines. The monazite comes mainly from biotite granite that forms the cores of mountain ranges extending from Burma through western Thailand into the Malay Peninsula, but the cassiterite and wolframite originated in quartz veins, pegmatite dikes, and aplite dikes related to the granite (Brown and Dey, 1955, p. 247–251; Griffith, 1956, p. 16).

Placer concentrates from Wan Hpa-lan (Wan Hapalam) in the Southern Shan States contain abundant monazite probably derived from nearby sources, inasmuch as many grains are small sharp-edged euhedral crystals (Chhibber, 1934, p. 240). In the Tavoy district monazite occurs with cassiterite in placers at Taungthonlon, in black sand on the beach 1 mile northwest of the mouth of the Kyanchaung, and at the mouths of streams entering the Heinze basin (Heron, 1917, p. 180). Samples taken by Heron (1917, p. 179; McMillan, 1918; U.S. Bur. Foreign and Domestic Commerce, 1918) at 28 localities on the Shwe Du Chaung and Lamawpyin Chaung, streams that drain the granite forming the Anatholin range in the Mergui district, contained from 0.2 to 6.3 pounds of heavy minerals per cubic yard of sediment and averaged 1.2 pounds. Ilmenite predominated in the concentrates; other minerals in order of abundance were monazite, magnetite, garnet, and zircon, and a few grains of gold and cassiterite. An analysis of a concentrate disclosed 1.61 percent of Re_2O_3 and 0.18 percent of ThO_2. No mineralogical analysis of the concentrate was published; hence, the quantity of thorium oxide in the monazite cannot be estimated with certainty. If it is assumed that the rare earths and thorium oxide in the concentrate are from monazite alone, then the monazite may contain about 7.0–7.5 percent of ThO_2.

The occurrence of monazite east and south of Burma in the tin placers in Thailand and the Federation of Malaya indicates that monazite probably has a far wider distribution in the granitic regions of Burma than is shown by the few reports. Analysis of the concentrate from Mergui and analyses of monazite from tin placers in Thailand and the Federation of Malaya suggest that monazite from Burma can be expected to have at least 5.0 percent of ThO_2. It probably contains thorium oxide, whereas the monazite from the tin placers far to the southeast on Belitung in the Republic of Indonesia do not (Hintze, 1922, p. 370).

Reports that were circulated early in 1948 about large deposits of thorium-bearing minerals in central and eastern Burma close to the border with Thailand seem to have been unfounded (Eng. and Mining Jour., 1948a; 1948b).

CEYLON

Monazite was first found in Ceylon about 1903 by J. W. Evans in sand from the Niriella Ganga (Dunstan, W. R., 1905, p. 19; Coomaraswamy, 1906, p. 198). By 1918 a small output was achieved from beach deposits, and in the 12-year period through 1929 at least 700 short tons of monazite was produced. Renewed interest in the beach placers in the early 1950's led to an annual output that reached 370 short tons of monazite in 1960 (J. G. Parker, written commun., 1962):

	Short tons		*Short tons*
1952	16	1957	150
1953	56	1958	124
1954	51	1959	94
1955	67	1960	370
1956	58	1961	239

Monazite from Ceylon contains an average of about 10 percent of ThO_2, which is several percent greater than the average of commercial monazite from sources elsewhere in the world (Mining Jour., 1914; Krusch, 1938, p. 77; Wadia, 1943, p. 9; Nag and others, 1944, p. 169). This high average for thorium oxide in the monazite is thought by the writer to reflect the uniformly plutonic character of the source rocks in Ceylon and is further interpreted by the writer to show that the monazite crystallized in the gneisses and schists when they were metamorphosed. This interpretation differs from the usual concept that the monazite in the gneisses is relict detrital grains (Coates, 1935, p. 132–152).

CRYSTALLINE ROCKS

Monazite occurs as small accessory grains in granulite, sillimanite gneiss, biotite gneiss, biotite-hornblende gneiss, and granite throughout much of Ceylon, but none of these occurrences is an economic source for monazite (Wadia, 1943, p. 8; 1944, p. 5, 8). Its distribution and abundance are closely related to the kind of host rock. A brief summary of this relation as described by Coates (1935, p. 115–165) is made in the following paragraphs.

Underlying the low country in the southeastern part of the island is the well-banded Bintenne gneiss. It is a coarse black and white gneiss composed of layers of clear quartz and white feldspar alternating with biotite-rich layers of granular quartz and feldspar. Locally nonbanded fine-grained grayish-white or pink gneiss poor in biotite is present. Accessory minerals are magnetite, ilmenite, zircon, and sparse monazite. Rocks of the charnockite series occupy the whole of the southwest quarter of the island. They were considered by Coates (1935, p. 138) to be igneous intrusives into highly metamorphosed sandstone, shale, and limestone. All the more silicic members of the charnockite series contain small quantities of monazite, and monazite is especially plentiful, possibly reconcentrated, in shear zones in charnockite. Graphite commonly forms veins in these shear zones. Sillimanite-garnet-orthoclase granulites in the southwestern part of the island contain accessory monazite, rutile, and zircon. The north half of the island is underlain by the Wanni gneiss group of red, pink, or buff gneiss and granulite of intrusive appearance. Locally this group forms long parallel bands between members of the charnockite series. The Wanni gneiss group is characterized by a paucity of ferro-magnesian minerals and an abundance of magnetite and monazite, the monazite at many places being megascopically visible. In accordance with its geographic distribution the Wanni gneiss group is divided into the Tonigala gneiss, the Kalkudah-Nilaveli gneiss, the Ritigala gneiss, and the Ambanpitiya gneiss; the Tonigala gneiss is the principal unit. Although the Tonigala gneiss is widely monazite bearing and is especially rich in monazite in the Kurunegala district at the west center of Ceylon (Wadia, 1941, p. 12–13; 1943, p. 8) and at Kaduwela, monazite is also notably common in the Kalkudah-Nilaveli gneiss. The Ambanpitiya gneiss contains the least monazite of the four units.

The crystalline rocks are cut by two distinctly different kinds of pegmatites characterized respectively by red and by white feldspars. The first kind consists of red orthoclase, colorless plagioclase, quartz, some biotite and magnetite, and a little monazite; they may be genetically related to the Tonigala gneiss. The second kind of pegmatites, in addition to white feldspars and quartz, commonly contains accessory zircon, monazite, thorianite, and beryl. Also found in a few pegmatites are thorite, allanite, fergusonite, xenotime, chrysoberyl, topaz, andalusite, rutile, cassiterite, ilmenite, and tourmaline. The second group of pegmatites are particularly common near Balangoda (Coomaraswamy, 1904, p. 418). They are younger than the charnockite series of rocks, but the relation of the charnockite series to the Wanni gneiss group is unknown.

Coates (1935, p. 165) said that the greatest concentration of monazite in the rocks of Ceylon was in the Balangoda group of pegmatites; however, the greatest resource of monazite seems to the writer to be in the Wanni gneiss group and in the sillimanite gneisses. Indeed, these sources seem to have supplied most of the monazite to the streams and beaches of Ceylon. As long ago as 1916, members of the Imperial Institute in London observed that the tiny anhedral grains of monazite in granulite at Nuwara Eliya identically resemble in size, shape, and composition the fine-grained monazite widely found in the streams (Imp. Inst. [London], 1916, p. 352). Similarity between the monazite in the granulite and the typical alluvial monazite was interpreted by the Institute to show that alluvial monazite in Ceylon is derived mainly from granulite instead of pegmatite.

Not many localities have been mentioned in the literature as examples of monazite in the crystalline rocks in Ceylon. Only where its occurrence in stream sediments was discussed could the pervasive distribution of monazite in the bedrock of Ceylon be fully appreciated.

Small amounts of monazite have been concentrated from samples of the Bintenne gneiss exposed at Hambantota, Komari, and Batticaloa in the southeastern and eastern parts of Ceylon (Coates, 1935, p. 117).

The schists, gneisses, and granulites, the silicic members of the charnockite series, and the granitic rocks in the southwestern and central parts of the island were the source of ilmenite-rich concentrates containing small amounts of monazite and variable quantities of zircon and rutile (Dunstan, W. R., 1907, p. 37). The approximate percentage of monazite in four concentrates from weathered bedrock in the vicinity of Ambawela Station was as follows:

	Percent
Pattipola	5
Totapola	2
Ambawela Station	.5
Ambawela Station	1

Megascopic crystals of yellow monazite were observed in gneiss at Ambalawa (Dunstan, W. R., 1914, p. 14, 22). Monazite is especially common in gneiss at Kamburupituya and Narandeniya (Dunstan, W. R., 1910, p. 50). Tiny anhedral grains of monazite in feldspathic granulite in charnockite near Nuwara Eliya contain 9.81 percent of ThO_2 (Imperial Inst. [London], 1916, p. 353). The granulite contains about 0.1 pound of monazite per cubic yard. Garnetiferous biotite augen gneiss between Nugatenna and Madugoda is monazite bearing.

Monazite was reported in the Wanni gneiss group in the north half of the island at only three localities. The Tonigala gneiss in the Kurunegala district is especially rich in monazite (Wadia, 1943, p. 8; 1944, p. 5, 8). A pink granite phase of the Tonigala gneiss forms a thin dike in charnockite near Kaduwela (Coates, 1935, p. 159). This phase contains megascopic monazite. Exposures of the Kalkudah-Nilaveli gneiss display megascopic monazite at Kalkudah (Coates, 1935, p. 160).

The Balangoda group of pegmatites have been reported to contain monazite in at least 11 localities, principally in the central and southwestern parts of Ceylon. Monazite was discovered in them by A. K. Coomaraswamy at exposures east of Teldeniya and nearby in dikes at Nugatenna (Coates, 1935, p. 164). It is also found in dikes at Balangoda, Denagama Estate, Nuwara Eliya, Ambalawa, localities southwest of Ratnapura, Aninkanda Morawak Korle, Muladuwanella Durayakande, Buluhela Oya in the Moon Plains, and at Hikkaduwa.

Monazite forms good crystals in pegmatite dikes that cut the sillimanite-garnet-orthoclase granulites at localities southwest of Ratnapura (Mining Jour., 1945). Two monazite pebbles, seemingly from pegmatites near Ratnapura, were analyzed by Johnstone (1914, p. 56; Imp. Inst. [London], 1914a, p. 56; Wadia, 1943, p. 9; Bowie and Horne, 1952, p. 2). Both pebbles were rich in thorium oxide, and one contained a remarkable 28.20 percent. An analysis by Kato (1958, p. 226) of monazite from Ratnapura showed 14.52 percent of ThO_2. Monazite pebbles, possibly also from pegmatite, found at Aninkanda Morawak Korle (Naminkanda) and Muladuwanella Durayakanda, Gilimale (Dunstan, W. R., 1906b, p. 34–35), were analyzed and found to contain 9.75 and 9.49 percent of ThO_2.

Chemical analyses, in percent, of monazite from Ceylon

[Analysts: 1, 2, 4, 5, Johnstone (1914, p. 56); 3, Kato (1958, p. 226)]

	1	2	3	4	5
Ce_2O_3	27.37	20.65	22.95	27.51	27.15
La_2O_3 (group)	30.13	21.63	30.56	29.59	29.59
Y_2O_3 (group)	2.14	.94	-------	2.54	3.93
ThO_2	10.29	28.20	14.52	9.75	9.49
U_3O_8	-------	-------	.32	-------	-------
P_2O_5	27.67	20.20	26.84	26.12	26.12
SiO_2	1.03	6.09	2.46	1.78	1.67
Al_2O_3	.17	.29	.43	.61	.17
Fe_2O_3	.81	1.13	.93	1.27	.87
CaO	.41	.10	.82	-------	.45
PbO	-------	-------	.20	-------	-------
Loss on ignition	.20	-------	.35	.59	.48
Total	-------	-------	100.38	-------	-------

1–2. Ratnapura. Specific gravity of 5.23 and 5.47, respectively.
3. Ratnapura.
4. Aninkanda Morawak Korle (Naminkanda). Specific gravity of 5.20.
5. Muladuwanella Durayakanda, Gilimale. Specific gravity of 5.25.

An orthoclase-quartz-mica pegmatite in charnockite exposed in a tributary to the Buluhela Oya in the Moon Plains was the source of fresh and weathered specimens of monazite that were analyzed (Imp. Inst. [London], 1916, p. 349–356). Both samples had about the same amount of thorium oxide, but the fresh monazite was rich in uranium oxide, whereas the weathered monazite had only a trace:

	Percent A	Percent B
Ce_2O_3, La_2O_3 (group), Y_2O_3 (group)	56.50	52.60
ThO_2	7.90	7.30
U_3O_8	2.66	Trace
P_2O_5	26.80	-------
SiO_2	1.92	2.08
Al_2O_3	.13	-------
Fe_2O_3	1.40	-------
CaO	.27	-------
Loss on ignition	2.20	-------

A. Clean monazite from pegmatite.
B. Altered monazite from same pegmatite. 86.5 percent of monazite and 13.5 percent of earthy coating.

The pegmatite at Ambalawa has sparse monazite and thorianite, and the dike at Hikkaduwa contains small amounts of apatite, fluorite, and monazite (Dunstan, W. R., 1914, p. 16, 18).

CONSOLIDATED SEDIMENTARY ROCKS

Sedimentary rocks of Miocene age form low cliffs along the northwest coast of Ceylon; and in the vicinity of Kudremalai, the cliffs are capped by red sandstone which contains ilmenite and monazite (Coates, 1935, p. 186). Erosion of these cliffs and deposition of the monazite has produced beach placers which are described in another section.

Pre-Recent quartz-laterite conglomerate forms the highest and oldest terrace deposit in the Kelani Ganga upstream from Colombo. Concentrates from this cemented conglomerate contain a trace of monazite (Imp. Inst. [London], 1916, p. 344–358).

A variety of consolidated sedimentary rocks of Recent age were reported by W. R. Dunstan (1910, p. 20, 35, 43, 62) to contain small amounts of monazite. Medium-grained sandstone at Pamunugama has detrital grains of garnet, spinel, ilmenite, rutile, zircon, hypersthene, sillimanite, and monazite. Ferruginous conglomerate at Kamburupitiya contains sillimanite, garnet, spinel, zircon, rutile, ilmenite, and monazite. Yellow sandstone veined with quartz and exposed at Kamburupitiya has a similar but not identical suite of heavy accessory minerals as the conglomerate. The sandstone lacks spinel and ilmenite and contains chlorite. Gritty limonitic ironstone laterite at Ambalawa consists of quartz, feldspar, magnetite, and ilmenite and small amounts of accessory monazite, garnet, biotite, and zircon. From the mineral composition this laterite seems to be a sedimentary rock enriched in heavy detrital grains and subsequently weathered. The description, however, was not clear.

FLUVIAL DEPOSITS

Monazite weathered from the crystalline rocks has been concentrated in Recent fluvial deposits along streams throughout Ceylon. Early surveys of the island disclosed small amounts of monazite accompanied at various places by zircon, sillimanite, garnet, rutile, ilmenite, thorianite, spinel, and corundum in practically every stream in the Central and North-Central Provinces and in many streams in the Western and Southern Provinces (Dunstan, W. R., 1907, p. 11–41; 1910, p. 7–70; 1914). Most of the monazite-bearing streams reported in the early surveys drained the region from Kurunegala south to Matara and from Colombo east to Badula. This distribution of reported localities seems to reflect the geographic extent of the surveys rather than the occurrence of monazite. Some 250 monazite-bearing fluvial deposits are listed in W. R. Dunstan's reports of 1907, 1910, and 1914, and of these localities, 227 can be identified in the Ceylon Gazetteer of the U.S. Board on Geographic Names. Distribution of these deposits given according to number of localities in a quadrilateral 10 minutes by 10 minutes is shown in table 12. The fluvial deposits of monazite are common in areas underlain by sillimanite gneiss, silicic members of the charnockite series, the Wanni gneiss group, and the second group of pegmatites in the central and southwestern parts of the island. More recent work has shown that monazite is very common in fluvial sediments in the Wanni area of northern Ceylon (Wadia, 1943, p. 8).

The reported fluvial deposits were said by W. R. Dunstan (1910, p. 3) to be too small or too low in grade to be economic sources for monazite. No state-

TABLE 12.—*Geographic distribution of monazite-bearing streams in Ceylon as determined by heavy-mineral reconnaissance from 1905 to 1910*

[Number of localities given for quadrilaterals 10 minutes by 10 minutes. Adapted from W. R. Dunstan (1907, p. 11-41; 1910, p. 7—70; 1914, p. 3—22)]

North latitude \ East longitude	79°	80°						81°				
	50′–59′	0′–9′	10′–19′	20′–29′	30′–39′	40′–49′	50′–59′	0′–9′	10′–19′	20′–29′	30′–39′	40′–49′
8° 39′–30′									1			
29′–20′												
19′–10′												
9′– 0′			1									
7° 59′–50′		1		1			1	1				
49′–40′						1	3					
39′–30′		1	1	1	4		2					
29′–20′		1		1	3							
19′–10′			6	2	3	2	3	2	1			
9′– 0′	1		2	3	7	2		2				
6° 59′–50′	2	2	9	2	5	11	7	5	1	1	1	
49′–40′	3	1	1	14	5	8	1	4	4			
39′–30′	1			10	4	4						1
29′–20′		3		3	6	1					1	
19′–10′			7	2	5	5	1					
9′– 0′		3	5		12	1	2	1				
5° 59′–50′					1	1						

ments were made in his reports of 1907, 1910, and 1914 about the area, thickness, or volume of the stream deposits in the valleys sampled.

Evidence for the opinion about grade was repeatedly presented by W. R. Dunstan in the mineralogical analyses of concentrates published in his reports of 1907, 1910, and 1914. In most of the concentrates monazite is one of the less abundant minerals. It commonly makes up 0.5–10 percent of the concentrate, is sparingly present in abundances of 11–20 percent of the concentrate, and exceptionally exceeds 40 percent of the concentrate (Dunstan, W. R., 1914, p. 3). Concentrates from gold placers at Karawita contain 90 percent of monazite (Dunstan, W. R., 1907, p. 19), an amount that is not exceeded by any other fluvial concentrate described from Ceylon.

Amount of monazite in the unprocessed stream sands was reported for only 9 of the more than 250 monazite-bearing samples described in the reports on the mineral surveys, and the amount for each sample was low (Dunstan, W. R., 1910, p. 16–18, 34; 1914, p. 17):

	Percent
Amugoda at Bahawagodo	0.009
Amugoda at Telagaspe	.0005
Elpitiya (avg of 5 samples of sand from gem pits)	.001
Elpitiya (sand from gem pit)	.007
Elpitiya (sand from gem pit)	.045
Elpitiya (sand from gem pit)	.014
Godamunna	.033
Moon Plains, at Nuwara Eliya	.004
Masmulla Kele	Very low tenor

Small amounts of gold are in about 10 percent of the stream deposits whose mineralogical composition has been described, and thorianite is about equally common (table 13). Cassiterite is present as a very minor accessory mineral in about 4 percent of the described fluvial concentrates. Most of the gem pits in river gravels also contain some monazite. None of these associations, however, seems adequate to compensate for the general low tenor of monazite in the placers.

Alluvial deposits in the valley and tributaries of the Kalu Ganga in the Ratnapura district of southwestern Ceylon have long been mined for gems, and, in the early years of the twentieth century, they were the source of some commercial thorianite, but they contain scant monazite. The best monazite deposits are in the valley of the We Ganga where concentrates have about 2 percent of monazite (Imp. Inst. [London], 1916, p. 331–344). Concentrates from another tributary, the Niriella Ganga, contain 6 percent of monazite and 0.5 ounce of gold per short ton of concentrate, and the terrace deposits contain less monazite than the lower deposits (Dunstan, W. R., 1907, p. 11).

TABLE 13.—*Minerals, in percent, associated with monazite in stream deposits in Ceylon*

[Reference: A, Dunstan (1907); B, Dunstan (1910); C, Dunstan (1914). Symbol used: P, present]

Locality	Reference	Page	Gold	Cassiterite	Thorianite
Alupola Oya	C	21	------	------	P
Bambarabotuwa Oya above Malwala	A	14	P	------	2
Batuwangala	B	10	------	------	P
Erabudhdeniya, Marapona	C	20	------	P	P
Etambe Dola Elapata	C	4	P	P	5
Galkandadeniya, Monrovia Estate	A	35	------	P	------
Getaheta Oya, Avissawella	A	26	P	------	P
Getaheta Oya near Sehela Oya	C	16	P	------	------
Halgolla Oya, Gampola	B	21	P	------	------
Halgolla Oya, Ulapane	B	62	P	------	------
Hiniduma, Galle district	B	11	P	------	------
Hunugedeniya, Ratgama	A	35	------	------	P
Kalu-ganga near Ratnapura	C	20–21	P	P	------
Karawita (Niriella Estate)	A	19	P	P	------
Kehelambuwa-wala, Ulapane	B	62	P	------	------
Kitulhane-amuwa, Ulapane	B	62	P	------	------
Kondurugala, Bambarabottuwa	B	55	------	------	P
Kotadeniya, Monrovia Estate	A	35	------	------	P
Kotmale Oya, Ulapane	B	62	P	------	------
Kudapandi Oya, Kondurugala	C	21	P	------	P
Lawpitiya Oya, Mapitagama	A	27	------	------	P
Mahaweli Ganga, Bintenna	C	11	P	------	------
Malwatta	B	40	------	------	P
Metihakka	B	39	------	------	0.75
Moon Plains	C	16	P	------	------
Moon Plains, Niriella Eliya	A	23	P	------	------
Narunkandure Dola, Dombagammana	A	30	P	P	P
Nelluwa district	A	36	P	------	P
Nelluwa district, Hinidum Pattu	A	35	P	------	P
Niriella Ganga	A	11	P	P	P
Panakuru Oya, Deraniyagala	A	34	------	------	P
Patambe Ela Hiniduma	A	35	P	------	------
Pelawatta Ganga	A	18	P	------	------
Pingawara	B	28	------	------	P
Rakwana Ganga near Huduman Kuda	C	54	------	P	------
Ranchagoda near Matara	C	16	------	------	P
Sehel Oya, Getahetta	A	27	P	------	P
Sitawaka Ganga, Avissawella	A	27	------	------	P
Sitawaka Ganga, Deraniyagala	A	34	------	------	P
Walawe Ganga, Morahela, Balangoda	A	14	9.5	------	43
Weganga	A	29	P	P	------
Weganga at Marapona	A	14	P	------	------
Weralupe-dola near Ratnapura	C	13	P	15.5	19

Gem- and monazite-bearing alluvial gravels are exposed at three levels in the lower valley of the Kelani Ganga upstream from Colombo. The highest and oldest gravel is a terrace deposit of quartz-laterite conglomerate. Concentrates from this weathered terrace material contain the merest trace of monazite. Concentrates from a younger terrace gravel exposed at altitudes between the old weathered terrace and the present paddies of the Kelani Ganga have 2–3 percent of monazite. The youngest and lowest gravel is buried beneath the sand and clay of the paddies and is the source of concentrates having as much as 28 percent of monazite. Farther along the Kelani Ganga, as far as the mouth of the Sitawaka Ganga, old gem pits produce few concentrates which contain more than 2 percent of monazite. Ilmenite is the dominant mineral in the concentrates, and the other minerals in order

238-813—67——5

of abundance are garnet, magnetite, hornblende, hypersthene, monazite, zircon, rutile, spinel, pyrite, sillimanite, sphene, anatase, and native platinum. Along the Sitawaka Ganga above its mouth to the first rapids upstream from Sitawaka village, the concentrates from alluvium consist of 70–80 percent of ilmenite, 1.5 percent of monazite, and a suite of other heavy minerals similar to those in the Kelani Ganga, except that tourmaline and corundum are present. The tenor in monazite in this part of the stream is only about 0.2 pound per cubic yard of sediment. Upstream from Sitawaka village the greatest tenors in monazite are 1 pound per cubic yard of sediment, monazite being about 5 percent of the concentrate. Inasmuch as the placer ground along the Sitawaka Ganga is shallow, is subject to frequent severe floods, and has been widely mined for gems, it is unlikely to be a commercial source of monazite.

Alluvial deposits explored east of Adam's Peak in the streams around Nuwara Eliya in the south-central and southeastern parts of Ceylon generally contain a little monazite (Imp. Inst. [London], 1916, p. 344–358), but this alluvium is less valuable for both monazite and gems than is that in streams farther west around Ratnapura. Gem pits at Pingarawa have produced specimens of black monazite (Dunstan, W. R., 1910, p. 29).

Monazite separated from other detrital minerals in the fluvial deposits of the Niriella Ganga was analyzed by Johnstone (1914, p. 56; in Imp. Inst. [London], 1914a, p. 56; in Wadia, 1943, p. 9) and found to have the following composition:

	Percent		*Percent*
Ce_2O_3	26.71	SiO_2	2.47
La_2O_3 (group)	30.06	Al_2O_3	.70
Y_2O_3 (group)	1.46	Fe_2O_3	1.09
ThO_2	10.75	CaO	.85
P_2O_5	24.61	Loss on ignition	.93

Detrital monazite from placers between Nuwara Eliya and Ambawela and from gullies in the Yalkumbura area southeast of Nuwara Eliya contains the following oxides:

[Analyst: Imp. Inst. [London] (1916, p. 355, 367)]

	Percent	
Ce_2O_3 (group)	63.62	60.12
ThO_2	4.96	4.91
U_3O_8	Trace	-------
SiO_2	1.88	-------

The amount of thorium oxide in the samples of detrital monazite from the Nuwara Eliya district is considerably less than the amount reported for monazite from feldspathic granulite in the same district. A small pebble of detrital monazite found at Pusse Dola, Dela, in Sabaragamuwa Province contains 14.31 percent of ThO_2 and has a specific gravity of 5.42.

Two determinations of ThO_2 and four determinations of U_3O_8 in monazite sand of unspecified provenance in Ceylon were reported by Satoyasu Iimori (1929, p. 230, 233) to have averages of 9.26 and 0.34 percent, respectively.

BEACH PLACERS

Beach placers where ilmenite, zircon, monazite, and rutile have accumulated are at the mouths of rivers emerging on the west side of the island and along most of the west coast of Ceylon (Nye, J. A., 1917; Soc. Chem. Industry Jour., 1917; Chem. Trade Jour. and Chem. Engineer, 1917a; 1917b; Imp. Inst. [London], 1917, p. 346; Coates, 1935, p. 183; Wadia, 1941, p. 18). About 2 percent of the heavy minerals from the beaches is monazite, which locally makes up 6–10 percent of the black sand and, in places, as much as 40 percent (Wadia, 1943, p. 8). Monazite in the beach placers is fine grained and rounded. No euhedral grains of monazite have been observed despite the common occurrence of euhedral zircon and rutile (Imp. Inst. [London], 1916, p. 326). Inasmuch as tiny round anhedral grains of monazite are a common accessory mineral in the granulites of the island and are washed from the granulites into the streams, the size and shape of the monazite grains in the beach placers are probably inherited.

For the most part, the concentrates seasonally form narrow bands at or just below the high tide line. Changes in prevailing wind and direction of coastal currents may destroy old deposits and form new ones. Only in a few places are the beach placers large enough to be of economic importance (Coates, 1935, p. 183).

The west coast from Colombo north to Mannar is low lying and is bordered on the east by sandstone and limestone of Miocene age (Coates, 1935, p. 186). Windblown sand is common along the coast, and in some regions, such ts the area north of Negombo, dunes extend inland for miles. Natural concentrations of heavy minerals are found at high tide level at the heads of small beaches, and they range in thickness from a mere film to several feet. The monazite in the beach placers has been reworked from low coastal cliffs of sandstone. At many places the heavy minerals are strikingly interbedded with white sand. Near the mouths of several streams, notably the Maha Oya where concentrates contain 7 percent of monazite and the Gin Ganga and Kalu Ganga where concentrates contain 4–5 percent of monazite, the heavy-mineral deposits are larger than ordinary (Wadia, 1941, p. 18; 1943, p. 8). Local peculiarities of the shore currents or wave action have led to concentrations of monazite that reach 3–9 percent of the heavy minerals at Marawila beach, 12 percent at Welaboda, and 22 percent at Kudremalai.

These rich deposits seem to be small. The one at Kudremalai, 40 miles south of Mannar, was reported by the Imperial Institute in London (1916, p. 327) to be only 200 cubic yards in volume, and was said by Coates (1935, p. 186) to contain no more than 100 short tons of monazite.

Southeastward from Colombo to Galle on the west coast and eastward from Galle to Hambantota along the south coast of Ceylon is a series of bays and headlands formed from plutonic rocks. Sand dunes occur in a few areas, especially around Hambantota, and sedimentary rocks or raised coral reefs fringe much of the shore. Many small steep beaches have narrow impermanent streaks of concentrates at the upper edge of the wave action (Coates, 1935, p. 185). Two distinct types of heavy-mineral deposits have been recognized along these shores (Imp. Inst. [London], 1916, p. 329). In one, ilmenite predominates; the deposit is black, and it contains abundant monazite. In the other, garnet is predominant; the deposit is red, and monazite is sparse or absent.

An unusually rich natural black sand from a bay at Kaikawala south of the mouth of the Bentota Ganga on the west coast contained between 40 and 50 percent of monazite. Concentrates from the deposit contain an average of 15 percent of monazite. The deposit follows the shore of a shallow bay between two headlands which are joined by a narrow bar, 0.5 mile long between the headlands and extending 2 miles north of the north headland. At certain seasons, particularly the change of the monsoon, good concentrates build up on the beach, but they never exceed a few inches in thickness. The placer was reported by Coates (1935, p. 185–186) to contain only 300 or 400 tons of monazite and was said to have been worked on a commercial scale for several years around the time of World War I, but records of output are not known.

Analysis of a natural concentrate containing 47.5 percent of monazite from the bay at Kaikawala showed 29.91 percent of the cerium earths, 4.15 percent of ThO_2 and 0.18 percent of U_3O_8 (Imp. Inst. [London], 1916, p. 330). Recalculated to 100 percent monazite, the amount of ThO_2 would be 8.7 percent.

A beach at Induruwa on the southwest coast was mined between 1918 and 1922, and about 3,000 tons of black sand containing 15 percent of monazite was extracted and processed. The deposits were not appreciably depleted, however, because after the mining was stopped fresh concentrates were formed by wave action (Fernando, 1948, p. 321).

A deposit on the beach south of the mouth of the Bentota Ganga, but not otherwise identified, was reported to have been the source of 299 short tons of monazite between 1918 and 1922 (Imp. Mineral Resources Bur., 1920, p. 7; 1924, p. 1; 1925, p. 5):

	Short tons
1918	22.4
1920	80.6
1921	84.0
1922	112.0
Total	299.0

Inasmuch as these records listed no other production from Ceylon during this period and the period was the time when the placer at Induruwa was mined, this output may be the actual production at Induruwa. Although the total is only about two-thirds as much as the estimate of production made by Fernando (1948, p. 321), a possible output for 1919 was not listed. It seems likely that this is the same deposit as the one said by Coates (1935, p. 185–186) to have been worked south of the mouth of the Bentota Ganga. Not all the black sand deposits on the southwest and south coasts are enriched in monazite. A large ilmenite deposit near Galle is practically devoid of monazite.

Along the east coast of Ceylon few but large deposits of black sand have been discovered. The two largest are not related to any present drainage system, and they contain only a trace of monazite. They are at Tirukkovil and Pulmoddai. At Tirukkovil about 45 miles south of Batticoloa ilmenite placers nearly devoid of monazite have formed for 3 miles along the beach from the Tirukkovil resthouse (Coates, 1935, p. 185).

The largest ilmenite deposits in Ceylon are at Pulmoddai on either side of the Kokkilai Lagoon 35 miles north of Trincomalee, but the placers have scant monazite (Coates, 1935, p. 183–185; Wadia, 1944, p. 8; Fernando, 1948, p. 320). The deposit is an old beach about 4 feet above sea level. It is 150 feet wide and 2 miles long; its seaward side slopes gradually down to low tide line. Black sand has been found for some distance offshore. On its landward side the black sand is covered with dunes. North of the old raised beach the modern beach is covered with black sand for 3 miles to the mouth of the Kokkilai Lagoon. According to Coates, the black sand is composed of 75 percent of ilmenite, 25 percent of zircon, and traces of magnetite and monazite. The placer was estimated by Davidson (1956a, p. 202) to contain at least 3 million tons of sand composed of 72 percent of ilmenite, 18 percent of rutile and zircon, and 0.4 percent of monazite.

The best monazite placers in Ceylon are on scattered beaches southward from Negombo to Galle along the west coast (Wadia, 1944, p. 8), and from these deposits a steady output was maintained from 1952 at least through 1961 (J. G. Parker, written commun., 1962). During 1920 shipments of 79 short tons of monazite were made (Vance, 1922), and in 1930 proposals were made to use the monazite at Induruwa as a source for helium for lighter-than-air craft (Mining Jour., 1930). Exports of monazite from Ceylon in 1927, 1928, and 1929, respectively, were reported as 168 short tons, 122 short tons, and 93 short tons (Mining Jour., 1930) or as 155 short tons, 112 short tons, and 85 short tons (Petar, 1935, p. 36). Despite these small discrepancies in statistics, Ceylon evidently was not a large producer of monazite.

CHINA

China seems to have produced no monazite, at least until 1952; however, by that time monazite had been identified among the heavy minerals in coastal and stream sands at several places in the southern, eastern, and northeastern parts of the country. In southern China, monazite in economically valuable amounts is associated with cassiterite in streams in the area of the tin-bearing placers that extends from the Chiang-hua hsien (Kianghwa district) in southwestern Hunan Province into the Chung-shan hsien (Chungshan district), Fu-ch'uan hsien (Fuchuan district), Ho hsien (Hoh district), and K'ung-chen hsien (Kungchen district) in northeastern Kwangsi Province (Peng, 1947, p. 111–115; Shen, 1956, p. 147). The placer monazite is derived from cassiterite-bearing granites that intrude limestone of early Carboniferous age and are overlain by Cretaceous sediments (Hsieh, 1943, p. 82). Eastern Kwangsi Province was reported by Shen to have alluvial monazite. Particularly extensive heavy-mineral deposits were said to occur along the beaches in the southern part of Kwangtung Province, but details were lacking (Zenkovich, 1960, p. 355). In eastern China, monazite has been found in the beach sand of Chin-men tao (Quemoy) and other islands along the coast of Fukien Province opposite Taiwan, in stream sand in I hsien of Ho-pei Province (Wong, 1919, p. 215; Hsieh, 1926, p. 238–239), on the beaches in Shantung Province opposite Korea, and along the coast of the Liaotung Peninsula in Liaoning Province, Manchuria, adjacent to northwestern Korea. In northern China, monazite has been found in Heilungkiang Province, Manchuria, near the Amur River.

A vein composed of fluorite, magnetite, pyrite, barite, and a rare-earth mineral resembling bastnaesite was found in 1933 in iron ore deposits at Beiyin Obo in Suiyüan Province 95 miles north of Pao-T'ou in Inner Mongolia (Ho, T. L., 1935, p. 279). Spectrographic analyses fail to reveal thorium, and mineralogical examination of the material did not disclose monazite. The veins are very abundant in the iron deposit and extend outward into limestone. Descriptions of the deposit were brief; the amount of rare earths in one vein to a depth of 330 feet was estimated as 1,700 tons, but the total amount of rare earths in the area was not mentioned. If the vein system is part of a carbonatite deposit, the resources in rare elements might be very large, and monazite may possibly be present in the area.

Monazite-bearing placers along the coast of Taiwan were discussed by Ichimura (1948), Chen (1953), C. S. Ho (1953, p. 203–211), and Shen (1956). Their reports showed that Taiwan is divided by a north-northeast-trending Central Range into a narrow, steeply sloping eastern side that leads to the Pacific Ocean and a broad, gentle western slope that steps down to the Formosa Strait. Souhward the flat western coastal area expands in width and is occupied on its seaward edge by tidal marshes. Northward the western coastal area contracts into a series of narrow river flats and lateritic terraces. A group of Pleistocene cones, called the Tatun volcanoes, rise abruptly at the north end of the island. Along the short east slope and in the core of the Central Range, schists, gneisses, and granitic rocks are exposed. Overlying the plutonic rocks on the west side of the island are Tertiary slates and unmetamorphosed Tertiary formations consisting of conglomerate, sandstone, shale, limestone, and some pyroclastic debris and flows.

Monazite occurs in the plutonic rocks of the Central Range. It is widely distributed in small amounts in the Tertiary sedimentary rocks where it is associated with heavy minerals derived from silicic igneous and metamorphic rocks. The plutonic core of the Central Range is regarded as a minor source of the heavy minerals in the Tertiary formations. The major source is inferred to be unexposed metamorphic monazite-bearing rocks that bordered the Tertiary basin of Taiwan. Stream and beach deposits derived from the plutonic rocks and Tertiary sediments also contain monazite. Small amounts of monazite have been detected (Ichimura, 1943, p. 1, 11, 20) in zirconiferous stream sands that originated in Pliocene basalt fields but were modified by detritus from nonvolcanic sources.

Three types of beach and stream placers were recognized by Chen (1953) and C. S. Ho (1953, p. 203–211). In one type of placer the monazite together with other heavy minerals is concentrated on the surface or under shallow overburden in sand and gravel along the beaches or in sand dunes near the coast. The most enriched parts are along the high tide line or the storm beach above the high tide line. These layers of black sand range in thickness from a fraction of an inch to about 1 foot. This type of placer has best formed along the north coast of Taiwan where the heavy minerals—composed of 80 percent of magnetite, 14 percent of ilmenite, 5+ percent of hypersthene, brown hornblende, rutile, and apatite, and less than 1 percent of zircon—are derived chiefly from the Tatun volcanoes. Monazite is generally absent from the beaches and dunes at the north end of Taiwan; but at one locality, Chienchowtze, Tanshui hsien, the heavy sand contains 0.04 percent of monazite. Contributions from Tatun volcanoes to the suites of heavy minerals in the beach deposits wane southward along the northwest coast. Monazite and other heavy minerals characteristic of granitic rocks and gneisses, reworked from the Tertiary sediments, become more dominant. The average composition of concentrates from beaches along the northwest coast is 50 percent of magnetite, 35 percent of ilmenite, 9 percent of zircon, 1 percent of monazite, and 5 percent of garnet, staurolite, tourmaline, rutile, and epidote. Beach and dune deposits are scattered along the length of the northwest coast and are particularly abundant in T'ao-yuan hsien (Taoyuan hsien) at Kuanyih where monazite makes up 0.45 percent of the heavy minerals. In Hsin-chung-li (Chungli hsien) at K'an-t'ou-tzu (Kantoutsu) and Pen-tzu-chiang (Pentzekang) the average amount of the heavy minerals is 4.5 percent of the beach sand and reaches 40 percent of the beach sand in some specially enriched layers. At K'an-t'ou-tzu and Pen-tzu-chiang the average depth of the deposits is 4 feet and the average tenor of the monazite is 0.8 percent of the concentrate. In beach deposits at Nanhaicha in Miao-li hsien (Miaoli hsien) and at Tashanchio in Houlung hsien, the amount of monazite reaches 1.2 and 2.0 percent of the concentrate, respectively. Along the southwest coast of Taiwan, dune deposits at T'ung-shan chou (Tungshanchow) and Hai-shan chou (Haishanchow) have 1.9 and 0.9 percent of monazite in the concentrates, and beach deposits at Hai-shan chou have 2.0 percent of monazite in the concentrates. The southward increase of monazite in beach deposits along the west coast is paralleled by an increase in the zircon and ilmenite and a decrease in the magnetite.

The second type of heavy-mineral deposit in Taiwan is formed in offshore bars deposited in elongated ridges 300–650 feet wide parallel to and 1–5 miles from the southwest coast. Eight bars totaling 20 miles in length have been explored between T'ai-nan hsien (Tainan hsien) and Yun-lin hsien (Yunlin hsien), and they were regarded by Chen (1953) as the most important heavy-mineral deposits on the island. The heavy minerals are concentrated in long strings at the high tide line on the seaward side of the bars. The heavy minerals are more abundant at places where the shore is slightly concave toward the land or where a channel or tidal inlet cuts the bar. The width of the bands of heavy minerals is ordinarily 30–65 feet, but on the bar at T'ung-shan chou the belt of concentrates reaches 325 feet in width. In these belts the bar sand contains enriched layers having 20 percent of heavy minerals at the top of the bar. The concentration decreases to 1 percent of heavy minerals at a depth of 3 feet. Black sand from bars off the southwest coast is composed of 9 percent of magnetite, 45 percent of ilmenite, 35 percent of zircon, 1.5 percent of monazite, and 9.5 percent of other minerals. Seven localities along the southwest coast listed by C. S. Ho (1953, p. 203–211) for placers in offshore bars, and the amount of monazite in concentrates from the bars, are as follows: North of the mouth of the Pei-chiang ch'i (Pekang-chi), 2.0 percent of monazite; mouth of the Pa-chang ch'i (Pachiang-chi), 2.1 percent; T'ung-shan chou, 1.7 percent; Wai-san-ting chou (Waisantingchow), 1.2 percent; Wang-yeh-chiang (Sinpeikangshanchow), 1.0 percent; Ch'ing-shan-chiang Shan (Chingshankangshan), 1.4 percent; and Wang-erh-liao Shan (Wantzeliaoshan), 1.0 percent.

The third type of placer is in streams. High-grade concentrates form thin layers on or near the upper parts of bars in the convex sides of bends in the middle or lower courses of streams that flow across the coastal plain in southwestern Taiwan. The average river bar contains less than 2 percent of heavy minerals, and areas of rich concentration shift from place to place following the regimen of the stream. The average composition of concentrates from streams on the southwestern coastal plain was given by Chen (1953) as 5 percent of magnetite, 25 percent of ilmenite, 55 percent of zircon, 2 percent of monazite, and 13 percent of other minerals. Four main streams, the Pei-chiang ch'i, the P'o-tzu ch'i (Potze-chi), the Pa-chang ch'i, and the Ts'eng-wen ch'i (Tsengwen-chi), rise in the plutonic rocks of the eastern highlands and flow across the Tertiary deposits to the southwest coast of Taiwan. The percentage of monazite in the heavy minerals from their principal monazite-bearing tributaries was given by C. S. Ho (1953, p. 203–211) as follows:

Tributaries to the Pei-chiang ch'i:	
Houkoutze	1.8
Yenshuinan	2.2
Hou-liao (Houliao)	1.7
Wan-lung (Wanti)	1.8
Tributaries to the P'o-tzu ch'i:	
Liang ch'i (Hsiashuang-chi)	1.9
Lin-nei (Linnei)	2.1
Weitzenei	2.3

Tributaries to the Pa-chang ch'i:	
Shang-ta ch'i (Shangtan)	1.5
Tung-kuo (Kuolutze)	1.8
Totzetou	1.6
Tributaries to the Ts'eng-wen ch'i:	
Tributary southeast of An-yeh (Anyeh)	2.0
Sutzu	2.8
Yung-lo (Tawenliao)	1.8

Concentrates from sediments in two streams effluent on the northwest coast, the Nan-k'an ch'i (Nankan-chi) and the Hung-mao chiang (Hungmaochuang), have 0.4 and 0.9 percent of monazite, respectively.

Monazite has been found in stream sand north of Hua-lien ch'i (Hualin) and in beaches along the east coast of Taiwan, but little is known about the nature of its occurrence (Ho, C. S. 1953, p. 203–211).

Particles of monazite and other heavy minerals from western Taiwan are generally not smaller than 0.05 mm nor larger than 0.5 mm. Most of the grains are between 0.08 mm and 0.25 mm, and the shape ranges from euhedral to round, depending upon the origin, transportation, and deposition of the grain. The monazite is pale yellow to honey yellow and less commonly brownish red, brown, gray, or nearly colorless. Analyses of monazite from Taiwan show abundances of the rare earths and thorium oxide that are within commercial requirements for the combined oxides, but the material analyzed may have contained several percent of ilmenite and zircon:

Chemical analyses, in percent, of monazite from Taiwan

Analysts: 1–4. Not given by Chen (1953) 5–6. Given by Shen (1956, p. 150) as Sinchu Research Inst., Taiwan and Associated Metals and Minerals Corp., U.S.A., respectively]

	1	2	3	4	5	6
Ce_2O_3			29.06			26.40
$(La, Nd, Pr)_2O_3$	59.66	64.89	27.36	56.54	57.60	58.31
Y_2O_3			2.95			-----
ThO_2	4.52	3.20	6.79	5.56	5.66	5.69
UO_2	-----	-----	.05	-----	-----	-----
P_2O_5	25.67	28.17	27.82	-----	27.95	-----
SiO_2	2.24	2.02	1.52	-----	1.33	-----
Al_2O_3	-----	-----	.33	-----	-----	-----
FeO	-----	1.07	-----	-----	-----	-----
Fe_2O_3	1.53	-----	1.39	-----	-----	-----
TiO_2	.48	.57	.55	-----	.15	-----
ZrO_2	1.09	2.07	Trace	-----	2.95	-----
$(Nb, Ta)_2O_3$	-----	-----	.04	-----	-----	-----
CaO	-----	-----	2.48	-----	-----	-----
MgO	-----	-----	.01	-----	-----	-----
PbO	-----	-----	.06	-----	-----	-----
H_2O+	-----	-----	.28	-----	-----	-----
Total	-----	-----	100.69	-----	-----	-----

1–2. Beach sand, western Taiwan.
3. Alluvium, Chi-lung Tao.
4. Beach sand, western Taiwan.
5–6. Offshore bar, western Taiwan.

Reserves of monazite in accessible areas of western Taiwan were estimated by Shen (1956, p. 150) to be 702 short tons along the northwest coast, 7,633 short tons in the offshore bars of the southwest coast, and 1,355 short tons in streams on the southwestern coastal plain. Neither the tenors nor the reserves in monazite are attractive for large-scale mining, and no production of monazite has been recorded. Some monazite might be recovered as a byproduct from small-scale mining of ilmenite, rutile, and zircon; however, this is unlikely. Pertinent in this connection is Shen's observation (1956, p. 147) that the Japanese produced about 200 short tons of zircon from placers on Taiwan between 1943 and 1945, but they did not attempt to recover monazite.

FEDERATION OF MALAYA

Malaya is underlain by sedimentary and volcanic rocks which range in age from Carboniferous to Triassic. They are widely intruded by granite. Associated with the granitic rocks as minor accessory minerals, or in veins, or in replacement deposits at the contacts between the granite and older rocks, are cassiterite, wolframite, scheelite, ilmenite, monazite, gold, and a variety of other heavy minerals (Penrose, 1903, p. 145; Scrivenor, 1906, p. 2; Greig, 1924, p. 12). The main source of monazite in Malaya, as in Burma, probably is the granite. The granite and older rocks are deeply weathered, in places as much as 500 feet deep (Paton, 1958, p. 2–A) and are locally overlain by Tertiary deposits and younger alluvial sediments. Residual deposits of commercial-grade monazite have been reported (Crawford, 1957a, p. 6) from Malaya, but the principal possible commercial source is detrital monazite eroded from the granite and older rocks and concentrated with cassiterite and other heavy minerals in eluvial and alluvial placers (Imp. Inst. [London], 1911b; Jarvis, 1947, p. 71). Some monazite-bearing tin placers reach great size (Fermor, 1950, p. 82–83). Monazite occurs in the heavy sands (amang) recovered in tin mining. It makes up as much as 50 percent of the heavy sands at Kuala Trengganu (Tringganu) on the east side of Malaya (Eng. and Mining Jour., 1906a). Analyses of monazite from the Malayan tin placers (table 14) show that the amount of ThO_2 ranges from 3.4 to 9.41 percent (Mining Jour., 1906; Soc. Chem. Industry Jour., 1922) in contrast to the thorium-free monazite found in tin placers in Indonesia (Hintze, 1922, p. 370) and tin veins in Bolivia (Gordon, 1944, p. 330).

Although monazite reportedly was not produced as a separate product before World War II, Fitch (1952, p. 111) noted that a little monazite probably was recovered in 1914 from the Sungei Badang in the Gambang placer tin field in Pahang. About 1930 some mived concentrates containing monazite were shipped by the Kramat Pulai Co., Ltd. The concentrates consisted of scheelite, cassiterite, pyrite, tourmaline, zircon, ilmenite, magnetite, green spinel, garnet, and monazite (Imp. Inst. [London], 1930, p. 366). In 1933 several

TABLE 14.—*Chemical analyses, in percent, of monazite from Malayan tin-bearing placers*

[Analysts: 1, 4. Not given by Krusch (1938, p. 77). 2, 3. Johnstone (1914, p. 57). 5, 6. Not cited by Imp. Inst. [London] (1906, p. 309); 5, recalculated from an analysis of sand having 41.6 percent of monazite and xenotime; 6, recalculated from an analysis of sand containing 23 percent of monazite. 7. Johnstone (1914, p. 57). Reported by Imp. Inst. [London] (1906, p. 306) to be opaque white monazite from a concentrate consisting of cassiterite, 65 percent; ilmenite, rutile, and magnetite, 16 percent; monazite, 13 percent; and columbite, 3 percent. 8. Not cited by Wadia (1944, p. 6). 9. J. Shelton (in Johnstone 1914, p. 57)]

	1	2	3	4	5	6	7	8	9
Ce_2O_3		33.74	} 64.05	{	29.34	} 63.8	{ 25.46	30.32	} 60.00
(La, Nd, $Pr)_2O_3$		32.53			34.49		32.72	26.86	
(Y, $Gd)_2O_3$		.91	2.40		4.53			2.13	2.82
Y_2O_3							2.80		
ThO_2	4–5	3.40	3.53	3.5	5.30	8.7	8.38	8.28	9.41
U_3O_8					.44				
P_2O_5		26.58	27.87		25.39	26.7	23.92		23.71
SiO_2		1.45	1.08				.92		2.20
Al_2O_3		.03	.07				2.78		} 1.13
Fe_2O_3		.65	.64				.84		
CaO		.33	.17				.61		.29
MgO					.12				
(Cu, Pb) O					.39				
H_2O							.14		
Loss on ignition		.94	.52				1.28		.94
Total		100.56	100.33	3.5	100.00	99.2	99.85	67.59	100.50

1. Baias Tujoh.
2. Puchong Babi, River Kenring, Perak.
3. Kulim, Kedah.
4. Perak.
5. Sungei Kemaman, Trengganu.
6. Dindings.
7. Sempan Tin Co., Pahang.
8. Malaya (locality not specified).
9. Kelantan.

consignments of black sand from the tin mines were shipped to Japan. In all they amounted to only 250 tons, of which 70–80 percent was ilmenite and the rest a mixture of minerals among which monazite occurred (Willbourn, 1933, p. 5). Beginning in 1935 a market opened for ilmenite, and the great piles of black sand stored from the tin mining began to be processed for ilmenite. The residue from the concentration of ilmenite was rich in monazite (Fermor, 1950, p. 96), but monazite as a separate product had not been shipped by 1940 (Harris and Willbourn, 1940, p. 29; Fermor, 1940, p. 80). During 1944 and 1945 the Japanese in Malaya produced 220 tons of monazite and 200 tons of a mixed monazite-zircon concentrate from these residues (Fermor, 1950, table 2; U.S. Bur. Mines, 1947). A few small shipments of monazite concentrate containing about 6.0 percent of Th_2O were said to have been made after 1945 (Davidson, 1956a, p. 203). Reported output of monazite in 1955 and 1956 was 274 short tons and 694 short tons, respectively (Eng. and Mining Jour., 1957, p. 152). Exports of monazite for the period 1951 through 1961 were reported by J. G. Parker (written commun., 1962) to have been as follows:

	Short tons		*Short tons*
1951	84	1957	549
1952	63	1958	479
1953	208	1959	264
1954	391	1960	47
1955	279	1961	780
1956	707		

JOHORE

Water-worn grains of opaque pale-gray and yellow monazite were found at Tingkil (Scrivenor, 1912, p. 3). A considerable amount of monazite is present in the concentrates from the Kambau mines in valley of the Ulu Sungei Payong, a tributary to the Sungei Sedili Besar 4 miles from Sungei Paloi on the China Sea coast (Willbourn, 1928, p. 27; Scrivenor, 1928, p. 128). These fine-grained concentrates were made by sluicing shallow soil on low hills underlain by granite of Mesozoic age near a contact between the granite and quartzite and shale of Triassic(?) age.

KEDAH

Concentrates from tin placers in the valley of the Sungei Karangan near Kulim contained 41 percent of monazite, 39 percent of ilmenite, and 20 percent of cassiterite (Scrivenor, 1912, p. 3; Willbourn, 1925, p. 84). The pure monazite, analyzed about 1911 at the Imperial Institute in London, contained 3.5 percent of ThO_2 (Scrivenor, 1928, p. 38). Heavy minerals in the placers in the Sungei Karangan are derived from granite intruded into phyllite and sandstone. Tourmaline-bearing aplite is common, and the aplite, granite, phyllite, and sandstone are cut by quartz veins carrying cassiterite, wolframite, and muscovite (Willbourn, 1926, p. 320). Off the coast of Kedah and Perlis, monazite is present in sand in the Pulau Langkawi (Fermor, 1940, p. 81).

KELANTAN

The monazite richest in thorium oxide in Malaya comes from streams in Kelantan. At an unspecified locality in Kelantan a sample of monazite analyzed by J. Shelton (Johnstone, 1914, p. 57) was found to contain 9.41 percent ThO_2. Scrivenor (1931a, p. 17) commented that if large quantities of this monazite could be discovered in an accessible locality, there would be a ready sale for it. Of further interest was Paton's (1958, p. 2–J) statement that the only extensive body of schists in Malaya occurs in northern Kelantan. Does the thorium oxide-rich monazite originate in the schist?

NEGRI SEMBILAN

Monazite is an accessory mineral in weathered granite or pegmatite exposed at Sungei Betong near Langkap (Willbourn, 1925, p. 84; Scrivenor, 1931b, p. 24). It forms dull pale-brown crystals having well-defined faces as much as 1 inch across which are weathered on the surface to opaque very pale brown or white. The weathered mineral contains about 6 percent of ThO_2. Detrital monazite is associated with ilmenite and rutile in cassiterite placers around Seremban (Jarvis, 1947, p. 71).

PAHANG

The panning of sand from the beds of streams in Malaya was a regular part of the geological surveying there. It was done to determine the distribution of gold and cassiterite. From about 1907 to 1938 brief notes on the mineralogical composition of individual concentrates were published in various annual reports by the Geologist of the Federated Malay States, but as far as the writer knows, no systematic compilations were published. Most of the records on the examination of concentrates collected before 1938 were lost in World War II (Fitch, 1952, p. 51). In 1939, 1940, and 1952 papers were published by J. A. Richardson, E. S. Willbourn, and F. H. Fitch presenting results of systematic studies of the heavy accessory minerals in the rocks, surficial deposits, and alluvium in parts of Pahang and Selangor. In the following review the notes on spot localities published in early reports are mentioned briefly and are followed by summaries of the work of Richardson and Fitch.

Monazite accompanied by columbite and xenotime occurs in tin ore from the Ulu Sempam placer area, Pahang (Scrivenor, 1907a, p. 42). The monazite is derived from granite and contains 8.38 percent of ThO_2 (Willbourn, 1925, p. 84, 100). North of Bundi on the Sungei Kemaman at the border with Trengganu, cassiterite concentrates have as much as 58 percent of monazite which contains 5.3 percent of ThO_2 (Scrivenor, 1907a, p. 42; 1907b, p. 866; 1931a, p. 19). A tributary to the Sungei Kuantan was the source of a monazite-bearing cassiterite concentrate which Scrivenor (1910, p. 3) viewed as marking an extension of the monazite deposits of the Sungei Kemaman into Pahang. The thorium oxide content of this monazite was 3.15 percent (Willbourn, 1925, p. 84). The monazite fraction from a concentrate taken at Gambang near the Sungei Kuantan contained only 0.62 percent of ThO_2 (Willbourn, 1925, p. 84). An identical value was also given by Willbourn for the amount of thorium oxide in monazite separated from a cassiterite concentrate originating in the Sungei Bisek, a tributary to the Sungei Serau. The analyzed material from Gambang may be mainly xenotime instead of monazite, because Fitch (1952, p. 53) described abundant yellow xenotime resembling monazite in the alluvial tin mine at Gambang and showed that it has less than 0.5 percent of ThO_2. Concentrates from Bentong have variously been reported to contain cassiterite, ilmenite, zircon, garnet, tourmaline, monazite, hornblende, epidote, wolframite, and scheelite (Scrivenor, 1910, p. 3; Willbourn, 1925, p. 84). Concentrates from the headwaters of the Sungei Lemoi east of the Cameron Highlands are rich in tourmaline, zircon, and ilmenite, have some epidote, leucoxene, monazite, apatite, and topaz, and have sparse to very rare rutile, garnet, and cassiterite (Willbourn, 1932, p. 7). Granite, aplite, and pegmatite are common in the drainage basins from which the concentrates were taken.

Heavy minerals commonly present in surficial deposits derived from the Main Range granite in the Raub area were found by Richardson (1939, p. 80) to be biotite, ilmenite, zircon, apatite, tourmaline, and leucoxene. Less common are pistacite, topaz, chlorite, magnetite, monazite, limonite, and cassiterite. Sparse heavy minerals are rutile including sagenite, anatase, pyrite, and arsenopyrite. A similar but much more restricted suite of heavy minerals was obtained from surficial deposits formed on the Gunong Benom Range granite in the Raub area. The suite does not include monazite. It consisted of common biotite, apatite, zircon, limonite, leucoxene, pyrite, and epidote and very sparse molybdenite.

Heavy minerals from surficial deposits formed on mafic and hybrid rocks associated with the Gunong Benom Range pluton in the Raub area are devoid of monazite. They include biotite, amphibole, epidote, apatite, leucoxene, sphene, limonite, chlorite, magnetite, pyroxene, pyrite, chalcopyrite, and allanite. Surficial materials on serpentine give monazite-free concentrates of ilmenite, leucoxene, chromite, picotite, limonite, magnetite, tremolite, pyrite, and pyrrhotite. In the

Raub area the sedimentary rocks contribute to the alluvium only a small amount of heavy minerals. These are ilmenite, leucoxene, limonite, and zircon.

Assemblages of heavy minerals in alluvium derived from amphibole schist are barren of monazite and include actinolite, pistacite, zoisite, clinozoisite, tremolite, hornblende, chlorite, pyroxene, ilmenite, leucoxene, limonite, garnet, pyrite, and pyrrhotite. Thermally metamorphosed sedimentary rocks in the aureole adjacent to the Main Range granite give associations of heavy minerals lacking monazite and having biotite, chlorite, rutile, andalusite, chloritoid, tourmaline, garnet, amphibole, and pyroxene. In the thermal aureole of the Gunong Benom Range pluton, monazite is absent, and biotite, pyroxene, garnet, actinolite, magnetite, tremolite, and pyrite are present (Richardson, 1939, p. 80).

The Raub area includes a large part of the Malayan gold belt, but gold was not observed in the concentrates taken from any of the rocks, though it is thought to occur in some of the igneous rocks. Scheelite and cinnabar are also sporadically present in the alluvium but were not discovered in concentrates from the rocks.

Monazite is a characteristic mineral of the Main Range granite, is widespread in small amounts, but is unlikely to be of commercial value in the Raub area. Old mine dumps from which monazite could be reconcentrated, as is done elsewhere in Malaya, are not present in the area (Richardson, 1939, p. 144).

Fitch (1952, p. 52) prepared 97 concentrates from stream sediments in the vicinity of Kuantan. Two slides of each concentrate were examined under a microscope, and estimates of the relative abundances of the heavy minerals in each concentrate were tabulated. The mineralogical composition of the 27 monazite-bearing concentrates are given in table 15.

Concentrates from rivers draining areas underlain by granite consist mainly of ilmenite, colorless prismatic zircon, cassiterite, tourmaline, and monazite. Andalusite is rare, and almandine, rutile, and topaz are sporadically present in small amounts.

In the Kuantan area, monazite occurs sporadically in the sedimentary rocks of early Carboniferous and Triassic(?) age and in the granites which intrude them. Monazite, however, is absent from the sedimentary rocks where they are dynamically metamorphosed to phyllites or thermally metamorphosed to spotted

TABLE 15.—*Mineralogical composition and bedrock sources of monazite-bearing concentrates from streams in the Kuantan area, Pahang, Federation of Malaya*

[Modified from analyses by Fitch 1952, p. 56, table 4. Symbols used: Ab, absent, P, present; VR, very rare; R, rare; VS, very scarce; S, scarce; C, common; VC, very common; A, abundant; VA, very abundant; F, flood. Abundances were estimated without grain counts, and the expressions for abundance were given by Fitch as a general guide without absolute values]

Rocks in the distributive province	Number of samples		Mineralogy of the monazite-bearing samples												Location of monazite-bearing sample (river)
	Monazite-bearing	Monazite-free	Andalusite	Chiastolite	Cassiterite	Garnet	Ilmenite and iron oxides	Monazite	Rutile	Topaz	Tourmaline	Zircon: White	Zircon: Purple	Other minerals	
Granite at Ulu Sungei Reman	1	12		S	R	VR	VC	VS			VR	R		Xenotime P	Anak Sungei Chereh.
Granite at Sungei Bakah	4	5			R	R	VA	VR			R	R			Sungei Anak Reman.
Do.					C		VC	R			R	R		Fluorite VR	Sungei Reman.
Do.					R		VC	VR	VR	VR	S	S			Anak Sungei Reman.
Do.					VS		A	R			R	VS		Xenotime P	Ulu Sungei Reman.
North and east sides of granite at Gambang	7	3			VC		R	S						Pyrite VR	Sungei Sangka Dua.
Do.							R	VA				R		Xenotime P	Anak Sungei Panching.
Do.					VR		S	C				C		Xenotime P	Do.
Do.			VR				R	VC			R	C		Xenotime P	Do.
Do.							R	F				R		Xenotime P	Do.
Do.					R		C	VC				R			Ulu Sungei Pandan.
Do.				R			F	R				R			Do.
South side of granite at Gambang	5	3	VR		VR	VR	C	C		S	VR	R		Epidote VR; Xenotime P	Sungei Tulang.
Do.			VR				VA	R		VS		VR		Xenotime P	Sungei Belat.
Do.					VC	VR	VS	S	VR			VS			Sungei Badang.
Do.					R	VR	R	VA				R			Do.
Do.				VR	R	VR	VS	VS	VR		VR	A			Sungei Gambang.
Granite at Bukit Beserah	0	3													Not specified.
Granite at Bukit Ketam	1	0	R				C	VC		R	VR	R		Xenotime P	Anak Sungei Longkang.
Sedimentary and metamorphosed sedimentary rocks of Lower Carboniferous age (no granite).	1	26	VR		VC		S	S	VR		VR	R	R	Xenotime P	Anak Sungei Reman.
Sedimentary and metamorphosed sedimentary rocks of Triassic(?) age (no granite).	0	4													Not specified.
Granite and sedimentary rocks (Lower Carboniferous).	3	12	VS	VS			A	R			VR	VR			Anak Sungei Charu.
Do.			R	R			A	S	R			R			Do.
Do.							VC	C				VR			Do.
Granite and sedimentary rocks (Triassic(?) in age).	5	2			R	R	VA	VR	R		R	R			Anak Sungei Taweh.
Do.			R		VS	VR	C	C			VR	R	VR	Xenotime P	Do.
Do.					R	VR	VA	R	R		R	VS	VR		Sungei Taweh.
Do.					R	VR	VA	R	R		R	R	VR	Xenotime P	Do.
Do.							VA	VR	VR	R	R	VS	VR		Do.

slate or schist in the aureoles of the granite plutons. The apparent abundance of monazite in the granites increases as the abundance of the iron minerals and garnet decreases in the concentrate. This feature probably reflects the variation in ilmenite, magnetite, and garnet more than it does an absolute change in the abundance of the monazite.

Xenotime is very common in concentrates from the granite at Gambang. In places it makes up as much as 60 percent of the concentrate. It is yellow and closely resembles monazite. A partial analysis showed the following characteristic components of xenotime (Fitch, 1952, p. 53):

	Percent
U_3O_8	0. 94
ThO_2	. 5–
Y_2O_3 (group)	57. 1

The granite at Ulu Sungei Reman is noteworthy for the presence of topaz and greisen and the abundance of tourmaline, but it is very poor in monazite (Fitch, 1952, p. 21). Only 1 concentrate of 13 is monazite bearing, and that one has the least amount of tourmaline.

PERAK

The first recorded discovery of monazite in crystalline rocks in Malaya was said by Scrivenor (1915, p. 2; 1928, p. 143; 1931b, p. 25) to have been made at a quarry south of Lenggong in northern Perak (Metal Industry, 1917). The actual date of discovery was not given. The quarry exposes a contact between a pegmatite dike and crystalline limestone. Large quantities of rock at the contact were collected, crushed, and panned; and the concentrate contained slightly hydrated and opaque monazite accompanied by either zircon or xenotime. Scrivenor thought the concentrate came from the pegmatite, but he did not exclude the possibility that a small amount of the monazite may have come from the limestone.

Monazite occurs in detrital tin concentrates in crevices between residual limestone pinnacles at Siak near Siputeh (Scrivenor, 1907a, p. 37; Imp. Inst. [London], 1911b). The monazite is not uncommon, and it is associated with cassiterite, zircon, rutile, brookite, pyrite, arsenopyrite, ilmenite, muscovite, and apatite. Stockworks of small veins in the limestone pinnacles are impregnated with crystals of cassiterite, fluorite, arsenopyrite, quartz, calcite, muscovite, and tremolite; but monazite is not present. Thus, the detrital concentrates between the limestone pinnacles contain minerals absent from the stockworks, but the source of these other minerals, including the monazite, was not reported (Scrivenor, 1907b, p. 843).

Monazite from the placer worked by the Malayan Tin Dredging Co. at Batu Gajah contains 6.5 percent of ThO_2 (Scrivenor, 1920, p. 5; Willbourn, 1925, p. 84). A few of many concentrates from the Sungei Siput area are monazite bearing. Principal minerals in concentrates from the Jalong Tinggi Estate, Sungei Terjol, and Sungei Tekuah are, in order of decreasing abundance, ilmenite, zircon, tourmaline, epidote, spinel, and garnet. Locally grains of monazite, pyrite, cassiterite, anatase, topaz, zoisite, hornblende, andalusite, and rutile occur. Black sand from tin placers at Baias Tujoh (Bajas Tujoh, Bias Tujoh, Bajas Puchab) in the Kampar district have 1.5 percent of monazite, and the monazite contained 4–5 percent of ThO_2 (Imp. Inst. [London], 1911b; Willbourn, 1925, p. 84).

Monazite occurs in granite and aplite at the scheelite mine of Kramat Pulai Tin, Ltd., in the Kinta valley at the village of Pulai 6.5 miles southeast of Ipoh. The geology of the mine was described in detail by Willbourn and Ingham (1933). Relations of the monazite have been summarized from that account.

The mine is in a natural amphitheatre carved in limestone where a band of schist 100 feet thick is interlayered with the limestone. The floor of the amphitheatre is a pavement on limestone eroded smooth by the sea and later dissected by streams and buried under cassiterite-bearing alluvium. The mine is near a contact between limestone and granite on the east side of the Kinta valley. The monazite-bearing granite and aplite are part of the Main Range granite batholith.

Orthoclase, microcline, quartz, and a little plagioclase, zinnwaldite, and biotite make up the granite. Accessory minerals are abundant zircon; sparse, but uniformly distributed, monazite; and scarce tourmaline, rutile, topaz, cassiterite, sphene, and thorotungstite. At the contact of the granite near the scheelite mine, there is more aplite than granite, and the aplite generally forms plutonic margins, although dikes of aplite are common in the granite. The aplite consists of feldspars and micas like those in the granite, and it contains accessory tourmaline, topaz, zircon, monazite, anatase, apatite, and cassiterite. Monazite is more abundant in the granite than in the aplite, and topaz is more abundant in the aplite than in the granite.

Monazite is not present in the limestone, which has been metamorphosed to marble. It is apparently also absent from the layer of schist although the schist contains cassiterite and topaz. The schist was formed from alternate layers of calcareous sand and silt which underwent crushing and thermal metamorphism. The schist consists of layers of pyroxene schist, biotite-muscovite-quartz-schist, andalusite-biotite-muscovite schist, and hornblende-pyroxene schist.

The aplite grades along strike into pegmatite dikes in which book muscovite is common and crystals of beryl and tourmaline are present. These pegmatites are cut by quartz veins which contain a little wolframite. No descriptions of accessory minerals in the pegmatite of the dikes were given. Both schist and limestone have contact zones along the walls of the aplite and pegmatite dikes; monazite was not mentioned as one of the minerals in the zones, although cassiterite is present.

The scheelite ore is a coarse-grained pegmatitic intergrowth of fluorite and scheelite in the limestone and schist. In the schist it contains a very small amount of quartz and pale-green mica. The ore contains no zircon, rutile, and monazite as observed in the granite and aplite, and was regarded by Willbourn and Ingham (1933, p. 472) as a low-temperature deposit. Deposition of the scheelite at low temperature is attributed to the presence of abundant fluorine. Apparently the monazite crystallized before the commencement of the late-stage mineralization.

Some years before Willbourn and Ingham studied the geology of this deposit near Ipoh, Scrivenor (1911, p. 2) described a concentrate from an unknown locality near Ipoh as containing 88.4 percent of columbite, 11.6 percent of cassiterite, and a few grains each of zircon, tourmaline, hematite, and monazite.

Other localities reported to be sources of monazite-bearing concentrates in Perak are Selama, Sungei Kenering (Kenring River) at Puchong Babi, the Sri Muka, Batang Padang, Rotan Dahan, and Papan (Imp. Inst. [London], 1911b).

SELANGOR

Monazite is a minor accessory mineral in the three varieties of granite in the Main Range in east-central Selangor (Willbourn, 1940, p. 39). Relative abundances of the accessory minerals were determined in 10 concentrates from each variety of granite. In decreasing order of abundance, the accessory minerals in coarse-grained porphyritic biotite granite are magnetite, tourmaline, zircon, fluorite, cassiterite, topaz, monazite, apatite, sericite, muscovite, epidote, clinozoisite, zoisite, pyrite, anatase, and andalusite; and accessory minerals in porphyritic epidote granite are magnetite, apatite, zircon, pyrite, muscovite, monazite, cassiterite, allanite, and tourmaline. Also in order of decreasing abundance, the accessory minerals in fine-grained tourmaline granite are fluorite, cassiterite, topaz, apatite, zircon, pyrite, muscovite, monazite, anatase, sericite, and andalusite. In total abundance of accessory minerals, the coarse-grained porphyritic biotite granite contained twice as much as the porphyritic epidote granite and four times as much as the fine-grained tourmaline granite.

Dynamically metamorphosed sedimentary rocks southwest of the granite contain no monazite (Willbourn, 1940, p. 35–36). Streams along the edge of the Kuala Selangor swamps in the vicinity of Bukit Ginting Prah contain a very small amount of cassiterite, zircon, tourmaline, ilmenite, magnetite, anatase, and monazite (Willbourn, 1940, p. 44).

TRENGGANU

Small amounts of monazite were reported to be obtainable from most, if not all, tin placers in Trengganu (Scrivenor, 1928, p. 143–144; 1931a, p. 19; Millington, 1928, p. 6). The reported occurrences are on the Sungei Kemaman; and, because that river forms the boundary between Trengganu and Pahang, the few descriptions were cited for Pahang in some of the literature.

INDIA

The largest monazite deposits in the world are the readily accessible placers in beach, bar, and dune sands along the west and east coasts of India (Wadia, 1950, p. 157; Imp. Inst. [London], 1933b, p. 379). Monazite was discovered in India in 1909 by C. W. Schomberg in sand along the Kerala and Madras (Travancore-Cochin) sector of the Malabar coast between Cape Comorin at the southwest tip of India and Quilon (in Krishnan, 1951, p. 298; in Brown and Dey, 1955, p. 279). Subsequent exploration exposed monazite placers, commonly near the mouths of streams, scattered northwestward along the west coast from Cape Comorin to the estuary of the Narbada River on the Gujarat coast west of Amod (Broach) (Wadia, 1956, p. 164). The most recent discoveries are the deposits at Ratnagiri, at Mormugão (Marmagoa), and along the Gulf of Cambay south of the Narbada. Investigations on the east coast of India disclosed monazite placers, possibly richer than those of the west coast, along the Madras shore from Cape Comorin northeastward at least as far beyond the Coromandel coast as Chilka Lake and the mouth of the Brahmani River in Orissa (Wadia, 1956, fig. 1). Other sites where monazite has been found on the east coast are Visakhapatnam, the mouths of the Godavari River, the vicinity of Negapattinam, and the vicinity of Tinnevelly (Tirunelveli) on the Gulf of Mannar.

The monazite in the beach placers along the southwest coast is concentrated with ilmenite, rutile, zircon, sillimanite, and garnet (Brown and Dey, 1955, p. 241). The heavy minerals are transported from inland to the sea by rivers, or they are deposited in the sea by the erosion of the coastal Warkilli (Varkala, Varkkallai, Warkalay) series of sedimentary rocks of Tertiary age (Chacko, 1917, p. 2). The Warkilli series overlies plutonic metamorphic rocks—mostly charnockite, leptynite, cordierite gneisses, biotite schist and gneiss, hornblende schist and gneiss, diorite, granite, and pegmatite—which are exposed in the Western Ghats and Mysore and which are the ultimate source of the monazite in both the Tertiary sediments and the present beaches. The plutonic rocks of the Western Ghats and similar rocks in the interior of the peninsula probably are the source of the heavy minerals at Ratnagiri and Mormugão. Metamorphic and igneous rocks in the interior are the source of the monazite in the estuary of the Narbada River (Wadia, 1956, p. 166). Monazite in placers along the east coast probably is derived from sillimanitic granulites in Madras and Orissa. An extension of these granulites is exposed in Ceylon and is the main source of monazite in placers on that island.

Monazite has not been commercially produced from the crystalline rocks of India. Indeed, as late as 1956 no primary deposit of adequate size and tenor for mining was known, although monazite-bearing garnetiferous biotite schist containing more than 17.9 percent of monazite was known in Travancore (Davidson, 1956a, p. 205–206). This rock is in a migmatite zone at Tadikarakonam (Thadikarenkonam). Exposures are poor, but the monazite-rich parts of the migmatite were thought by Davidson to be 100 feet wide and to extend intermittently along strike for nearly a mile. Davidson (1956a, p. 206) estimated that the deposit might yield 100–200 tons of thorium per foot of depth from monazite which contains 10.7 percent of ThO_2. In 1956, the plans of the Rare Minerals Survey Division of the Indian Atomic Energy Commission included studies of the distribution of primary sources of monazite (Wadia, 1956, p. 166).

The commercial sources of monazite are the beach placers. Between the time mining began in 1911, when 932 short tons of monazite was produced until 1961, a total of nearly 100,000 short tons was produced. Peak output was 5,848 short tons in 1938.

Reserves of placer monazite in India were conservatively estimated by Wadia (1956, p. 164) to be 2 million tons. The resources in monazite must be many times as great as the estimated reserves because the monazite has been considered as a source of phosphate for fertilizer (Kartha, 1955, p. 53; Nair and Moosath, 1955, p. 63).

CRYSTALLINE ROCKS

Few descriptions of the occurrence of monazite in the crystalline rocks of India were found by the writer. A summary of the data follows.

KERALA

A thorium-rich mineral having monazite structure occurs in pegmatite in granite gneiss at Kuttakuzhi about 23 miles east-southeast of Trivandrum near the border with Madras. The mineral, which was named cheralite by Bowie and Horne (1952, p. 2), has a specific gravity of 5.28 and has the following composition:

[Analyst: Radiochem. Div., Chem. Research Lab., Teddington, England (in Bowie and Horne, 1952, p. 2)]

	Percent		Percent
Ce_2O_3	14. 21	Al_2O_3	Trace
La_2O_3 (group)	13. 35	Fe_2O_3	Trace
Y_2O_3 (group)	-----	CaO	6. 30
ThO_2	31. 50	PbO	. 92
U_3O_8	4. 05	H_2O+	. 06
P_2O_5	26. 80		
SiO_2	2. 10	Total	99. 29

In 1914, a thorium-rich material similar to cheralite was collected from Cootykad Pothay in Vilavancod Taluk near the locality where the cheralite was later discovered (Brown and Dey, 1955, p. 278).

Monazite from graphite-rich pegmatite in the Vellanad (Vellanaud) graphite mine, Travencore, contains 6.0 percent of ThO_2 . Monazite from quartz pegmatite and mica pegmatite at Esanthimangalam in the Thovala Taluk was analyzed by Venkitachalam Iyer who found 9.2 and 8.7 percent of ThO_2, respectively (in Chacko, 1917, p. 8; in La Touche, 1918, p. 391). Monazite was also reported in graphite-bearing pegmatite at Tadikarakonam about 14 miles northwest of Nagarcoll (Mining Jour., 1911). This pegmatite is in charnockite and leptynite. Pegmatites containing monazite and zircon have been reported at Kalkulam Taluk (Mining Jour., 1947a).

MYSORE

An often described, deeply weathered pegmatite dike exposed about 200 yards west of the 3/5 furlong stone near Yadiur (Yediyoor, Yedur, Yediyur) on the road from Bangalore to Kankanhalli was discovered to be monazite bearing by L. Subba Rao in 1912, and mining was begun for monazite in 1916–17 by V. S. S. Iyer of the Geological Department of Mysore State (Memminger, 1917a; Sen, 1935, p. 30; Ramaswamy, 1945, p. 81). The pegmatite is about 25 feet thick. It has well-defined zones consisting of a wall zone, intermediate zones, and quartz core. It is emplaced in granitic gneiss that contains xenoliths of greenstone. Other pegmatite dikes and veins of aplite cut the gneiss. Monazite in the pegmatite is reddish brown, has a resinous luster, and occurs sporadically. Relations of the monazite to the zones in the dike have not been described in detail, but apparently it occurs both with beryl in the quartz core (Rama Rao, 1942, p. 175) and with feldspar, quartz, muscovite, samarskite, and columbite in other zones (Ramaswamy, 1945, p. 81–82). By 1917, mining for monazite was halted because the quantity was small and the tenor of the monazite in ThO_2 was only 2.25 percent (Smeeth and Iyengar, 1916, p. 191–192; Memminger, 1917b). In 1941, mining of the dike for beryl began, and the monazite was again reported to be too sparse to be economic (Rama Rao, 1942, p. 180). A chemical analysis of the monazite was made by the Chemical Research Laboratory in Teddington, England, and the results, in percent, given by Arthur Holmes (1955, p. 85) were 3.91 for ThO_2, 0.22 for U_3O_8, and 0.38 for PbO.

This monazite from Yadiur has a Th/U ratio that is nearly 50 times greater than the ratio of 0.37 determined by Aithal (1955, p. 523) for monazite from an unspecified pegmatite in Mysore.

Quartzose gneiss on the west side of the Kolar schists near the Bangarapet (Bowringpet) Road contains visible red monazite, but the monazite is uncommon (Smeeth and Iyengar, 1916, p. 191–192; Memminger, 1917b).

Considerable prospecting for monazite was done about 1916–17 along streams in the Kadur and Hassan districts of Mysore and elsewhere in areas underlain by charnockites. Small amounts of monazite were found in several places, but economic deposits were not discovered (Memminger, 1917b).

ANDHRA PRADESH

Lit-par-lit veins of pegmatite and lenticular masses of pegmatite in sillimanite gneisses underlying the red loam of the Waltair Highlands in the Visakhapatnam (Vizagapatam) district contain monazite and zircon (Mahadevan and Sathapathi, 1948). The pegmatite veins consist of gray, pink, and white feldspars, white and blue quartz, biotite, iron-bearing minerals, zircon, and two varieties of monazite. One variety of monazite is greenish yellow; the other is dark green and has a submetallic luster.

Heavy minerals from two samples of mafic charnockite, one sample each of intermediate and silicic charnockite, and two samples of leptynite from the hills near Padmanabham about 10 miles from Bhimilipatam in the Visakhapatnam district were studied by Sastry (1954). The total amount of heavy minerals was greatest in the more mafic charnockite, decreased in the intermediate and silicic charnockite, and was least in the leptynite. Monazite was present only in the leptynite (table 16).

BIHAR

Pegmatites in the Gaya district have been the source of several specimens of monazite used for partial or complete chemical analyses. A complete analysis made by Sarkar showed the following amount of thorium oxide in monazite having a specific gravity of 5.16 from mica pegmatite at Singar in the Gaya district (Holmes, Arthur, 1949a, p. 297; 1949b, p. 20; 1950, p. 21; 1955, p. 92–93; Palache and others, 1951, p. 694):

[Analyst: Sarkar (1941, p. 247)]

	Percent		Percent
Ce_2O_3	22.00	CaO	0.83
$(La, Nd, Pr)_2O_3$	32.72	MgO	.09
Y_2O_3	1.15	MnO	Trace
ThO_2	12.00	PbO	.5331
U_3O_8	.2677	C	Trace
P_2O_5	27.22	H_2O-	.15
SiO_2	1.56	H_2O+	.48
Al_2O_3	1.20		
Fe_2O_3	.44	Total	100.64

TABLE 16.—*Heavy minerals, in percent, in charnockite and leptynite from Visakhapatnam, Andhra Pradesh, India*

[Analyst: Sastry (1954, p. 151). Symbol used: ----, absent]

	Charnockite				Leptynite	
	Mafic		Intermediate	Silicic		
Zircon	2.0	1.7	3.0	6.3	4.7	6.0
Apatite	1.3	1.7	7.3	4.7	3.0	3.3
Sphene	1.7	1.3	----	2.7	3.3	3.7
Monazite	----	----	----	----	2.0	2.3
Hypersthene	44.0	45.0	58.0	75.3	27.7	36.0
Hornblende	11.3	19.3	----	----	----	----
Diopside	28.7	23.3	----	----	----	----
Garnet	----	----	25.3	6.3	32.2	25.7
Sillimanite	----	----	----	----	6.9	5.7
Biotite	2.0	2.3	4.7	2.7	11.3	8.7
Opaque minerals	9.0	5.4	1.7	2.0	8.9	8.6

At Pichhli in the Gaya district, monazite containing 9.95 percent of ThO_2 is associated with pitchblende, torbernite, autunite, apatite, and columbite in a pegmatite in garnetiferous mica schist (Tipper, 1919, p. 259–260). Small amounts of monazite and zircon occur in pink gneiss about a mile east of Bangaikalan in the Hazaribagh district (Krishnan, 1958, p. 135).

RAJASTHAN

Arthur Holmes (1949a, p. 293) reported that a muscovite pegmatite of post-Delhi age at Soniand (Soniana) was formerly mined for monazite. The locality was shown by Gupta (1934, pl. 21, p. 152) to be in a band of gray micaceous phyllite locally containing garnetiferous schist of the Aravalli system. An analysis by A. A. Smales showed the monazite to be very rich in thorium oxide (Holmes, Arthur, 1949a, p. 294; 1949b, p. 19; 1955, p. 96):

	Percent
ThO_2	18.75
U_3O_8	.79
PbO	.567

CONSOLIDATED SEDIMENTARY ROCKS

Monazite-bearing sandstone and lignite in the Warkilli Series of Tertiary age are exposed between Varkkalli and Anjengo on the Malabar coast. Ash from the lignite contains monazite (Masillamani and Chacko, 1913, p. 699). Beach placers in the area have concentrated monazite and other heavy minerals released by the erosion of the sandstone.

Yellowish-brown ovoidal grains of monazite are present, but very sparse, in red and yellow ocher and white clay in laterite in the Sohawal area of Madhya Pradesh (Sharma and Purkayastha, 1934). The white clay and red and yellow ochers form fine laminae in laterite which caps hills underlain by sandstone. At places the laterite is indistinctly stratified and more or less clastic, but no fragments of the underlying sandstone are found in the laterite. The white clay and the ochers contain almost identical assemblages of heavy minerals, but the assemblages are different from those in the sandstone (table 17). Presumably the rocks from which the clay and ochers formed are different from the sandstone, but their original character is not known.

TABLE 17.—*Heavy minerals in clay, ocher, and sandstone in Madhya Pradesh, India*

[Modified from Sharma and Purkayastha (1934, p. 50). Symbols used: A, abundant; VC, very common; C, common; S, scarce; VS, very scarce; R, rare; VR, very rare]

	White clay	Red ocher	Yellow ocher	Upper Bhander sandstone	Upper Rewah sandstone
Magnetite and ilmenite.	C	A	A	VC	C
Tourmaline	VC	S	S	VS	VS
Zircon	VC	C	C	VS	VS
Kyanite	VR	VS	VS	------	------
Staurolite	VS	C	C	------	------
Rutile	S	S	R	VR	------
Garnet	VR	VR	VR	VR	VR
Andalusite	------	VR	------	------	------
Fluorite(?)	------	VR	------	------	------
Monazite	VR	VR	------	------	------
Zoisite	------	VR	VR	------	------
Chloritoid	R	VR	VR	VR	VR
Muscovite	VR	R	------	S	------
Hornblende, green	------	------	------	VR	------

FLUVIAL PLACERS

Fluvial placers from which monazite and other commercially useful minerals could be recovered economically probably exist in India, but none has been mined. Wadia (1956, p. 166) prepared estimates of the amount of thorium available in India which show fluvial placers as a possible source for small amounts of monazite even though they have lower concentrations of monazite than the beach placers. Few monazite-bearing stream deposits have been described.

Stream concentrates from Idar in central India were said by Tipper (1914, p. 195) to have a little monazite. Many streams in Mysore have been sampled, and locally monazite was found, but no commercial alluvial deposits were discovered (Smeeth and Iyengar, 1916, p. 191–192). A deposit of ilmenite, monazite, and zircon in Andhra Pradesh about 45 miles northeast of the railroad between Nander and Nizambad was shown by Wadia (1950, p. 158–159) on a map of the mineral localities of India. The kind of deposit was not specified, but the assemblage of minerals is typical of placers. Streams flowing from the Waltair Highlands to the coast of Andhra Pradesh are monazite bearing (Mahadevan and Sathapathi, 1948).

Large alluvial deposits of monazite associated with ilmenite, rutile, sillimanite, columbite, tantalite, and magnetite were found in the late 1950's in the Purulia district in Bihar and the Ranchi district in West Bengal (U.S. Bur. Mines, 1959). About 12 miles northwest of Purulia in the vicinity of Kataholdih, monazite-rich sand is as thick as 10 feet and has an average thickness over an area of 5 square miles of slightly less than 3 feet.

BEACH PLACERS

The commercial monazite deposits of India are natural concentrations of monazite with ilmenite, rutile, zircon, sillimanite, and garnet in the beach placers. At favorable localities, tidal currents and waves selectively remove minerals of low specific gravity and leave behind minerals of high specific gravity. Concentrations in which monazite is as much as 46 percent of the beach sand have been observed on the Travancore coast (Imp. Inst. [London], 1911a, p. 103), but ordinarily the monazite makes up less than 10 percent of the beach sand, possibly about 2–3 percent of the raw sand (Wadia, 1956, p. 164; Brown and Dey, 1955, p. 278; Kartha, 1955, p. 53). The raw black sand, however, contains 50–90 percent of ilmenite, an amount that exceeds any other yet discovered (Brown and Dey, 1955, p. 241; Gillson, 1957, p. 554; Hess, 1937a, p. 902–903). Concentrates processed from the black sand have 3–30 percent of monazite (Imp. Inst. [London], 1935b, p. 356). Sand dunes near the Travancore coast contain monazite and at places are mined with the beach placers. Locally the dunes are cemented by calcium carbonate into compact masses. Other monazite-bearing cemented sedimentary rocks exposed along parts of the Travancore coast are the ferruginous grits of the Warkilli Series (Tipper, 1914).

KERALA

Monazite was discovered in the Travancore-Cochin sector of Kerala and Madras in 1909 by C. W. Schomberg. For many years monazite was mined from the beach around Manavalakurichi between the old port of Colachel and the lighthouse on the point at Muttam (Viswanathan, 1946, p. 22–24). In 1933, mining shifted to deposits north of Neendakara (Nindakara) 6 miles north of Quilon. Commercial minerals that were exploited include monazite since 1911, ilmenite and zircon since 1922, garnet and sillimanite since 1936, and rutile since 1939. Baddeleyite was discovered in 1936 in the sands at Manavalakurichi, but commercially feasible separation was not possible as of 1962. In order of decreasing abundance, the heavy minerals in the beach sand are ilmenite (80 percent), zircon, sillimanite, rutile, monazite, and garnet.

The heavy minerals are reconcentrated by wave, current, and wind action in barrier bars, beaches, and dunes from sediments transported to the coast by rivers that drain the Warkilli Series of sedimentary rocks. The largest of these streams, the Kallada River, empties into Ashtamudi Lake, which is separated from the Arabian Sea by the Neendakara Bar.

The rocks of the Warkilli Series are intermediate host rocks for monazite between the original source rocks and the beach placers in the Quilon area, but at Cape Comorin the monazite was said to come from direct disintegration of gneiss (Masillamani and Chacko, 1913, p. 699).

In the literature analyses commonly list the amount of thorium oxide in monazite from the Kerala coast, but few analyses give the abundances of the rare earths. The amount of thorium oxide in fine-grained monazite has been reported from 15 beach placers, and it has been determined in monazite from 3 subaerial detrital deposits from Kerala. The results of these analyses together with the abundance of the monazite in concentrates from the beaches are given in table 18.

Partial analyses of monazite from the beaches made by W. A. K. Christie showed 1.55 percent of SiO_2 and 6.0 percent of ThO_2 in handpicked material and 8.5 and 10.08 percent of ThO_2 in magnetically separated samples of monazite (Chem. Trade Jour. and Chem. Engineer, 1915).

TABLE 18.—*Abundance of monazite and amount of thorium oxide in the monazite, in percent, in ilmenite concentrates from beach placers on the Malabar coast of Kerala and Madras, India*

[Analyses: 1–2, by Imp. Inst. [London] (1911, p. 103–105); 3–15, by Imp. Inst. [London] (1935b, p. 355–356); 16–18, Venkitachalam Iyer (in Chacko, 1917, p. 1–17). Symbol used: n.d., no data]

		Monazite	ThO_2
1	Beach near Quilon	n.d.	8.5
2	do	n.d.	10.08
3	Beach, 7th milestone on road from Quilon to Chavara.	6.4	8.30
4	Neendakara, north of bar	33.7	8.46
5	Neendakara, south of bar	12.9	7.44
6	Tiruvellauram	5.0	6.57
7	Varkkalli	6.0	7.96
8	Kurumbantura	3.3	8.54
9	Kodimuna	16.0	8.09
10	Pudur	3.1	8.01
11	Manavalakurichi, mouth of Valliar River	3.3	8.60
12	Muttam	7.3	8.18
13	Cape Comorin	6.3	9.23
14	Leepuram (Muttamtura)	19.9	9.24
15	Leepuram (near lighthouse)	4.6	8.68
16	Subaerial detrital monazite, Travancore	n.d.	4.9
17	do	n.d.	4.0
18	do	n.d.	5.5

A partial analysis showing 0.35 percent of U_3O_8 and 9.78 percent of ThO_2 in monazite from beach sand in Kerala was made by the Chemical Research Laboratory in Teddington, England (Holmes, Arthur, 1955, p. 102).

A partial analysis of detrital monazite from the Kerala coast made by Kartha (1955, p. 54) disclosed the following composition:

	Percent
RE_2O_3	61.73
ThO_2	8.73
P_2O_5	27.00
Insoluble residues	1.40

Analyses showing the rare earths and thorium oxide in two samples of Kerala placer monazite were given by Johnstone (1914, p. 57; Imp. Inst. [London], 1914a, p. 57):

	Percent	
Ce_2O_3	31.90	61.11 (combined)
La_2O_3 (group)	28.00	
Y_2O_3	.46	.62
ThO_2	10.22	8.65
U_3O_8	.37	-------
P_2O_5	26.82	26.50
SiO_2	.90	1.00
Al_2O_3	.17	.12
Fe_2O_3	1.50	1.09
CaO	.20	.13
Loss on ignition	.46	.45
Total	101.00	99.67

According to Kremers (1958, p. 2), the average commercial monazite from Kerala contains 59.5 percent of RE_2O_3 and 8.5 percent of ThO_2.

A complete analysis of the rare earth and thorium oxide precipitate from placer monazite from Kerala was published by Murata, Rose, and Carron (1953, p. 294). Their published analysis showed that the sum of the rare earths plus thorium oxide was equal to 100.6 percent of the precipitate. The precipitate equaled 67.82 percent of the monazite (K. J. Murata, H. J. Rose, Jr., and M K. Carron, oral commun., 1958). If the precipitate is recalculated to equal 67.82 percent, the composition is as follows:

	Percent
La_2O_3	12.94
CeO_2	28.31
Pr_6O_{11}	3.44
Nd_2O_3	12.07
Sm_2O_3	1.89
Gd_2O_3	.54
Y_2O_3	.27
ThO_2	8.36
Total	67.82

The average value of thorium oxide in the 26 listed analyses of monazite from the Malabar coast of Kerala and Madras is 8.1 percent. If the three lowest values (the analyses of subaerial detrital monazite) are omitted, the average abundance of ThO_2 in this monazite is 8.5 percent, which is the value given by Kremers (1958, p. 2) for commercial monazite from Kerala. This average is more realistic than the average of 7 percent of ThO_2 suggested by Krusch (1938, p. 75), or the average of 9–10 percent of ThO_2 quoted by Nag, Das, and Dasgupta (1944, p. 169), or the 10 percent mentioned by Petar (1935, p. 16).

Few of these analyses show the abundance of uranium in monazite from India, but even these few are adequate to show that the detrital monazite on the beaches is not unusually rich in uranium. The published analyses show that the monazite contains 0.2–0.46 percent of U_3O_8 (Wadia, 1956, p. 164).

In 1911, seven monazite deposits between Cape Comorin and Quilon were estimated to contain at least 18,000 tons of monazite (Mining Jour., 1911). By 1960, nearly 100,000 tons of monazite had been recovered, and estimates of the probable reserves of monazite in Travancore had reached 1.2 million tons (Grund, 1956, p. 1547). Reserves of thorium in monazite placers along the west coast of India and in the alluvial deposits were estimated to be 500,000 tons (Mining World, 1959, p. 85).

GUJARAT

Recent discoveries show that monazite in coastal deposits extends northwest to the estuary of the Narbada River on the Gujarat coast of India (Wadia, 1956, p. 164). Apparently, the source of the monazite in the most northwesterly deposits is plutonic rocks upstream on the Narbada to the northeast of the Deccan trap and the Delhi and Aravalli belts north of the Gulf of Cambay.

Original analyses of monazite from the Gujarat coast are lacking, but the monazite was reported to have from 5 to 11 percent of ThO_2 (Wadia, 1956, p. 164; Canadian Mining Jour., 1955).

MADRAS AND ANDHRA PRADESH

Monazite placers possibly richer than those of Kerala have formed along the Madras coast northeastward from Cape Comorin to the border with Orissa (Mining Jour., 1947b; Wadia, 1956, fig. 1). The principal localities in Madras and Andhra Pradesh are the coast at the Gulf of Mannar, Negapattinam, the mouths of the Godavari River, and the area at and north of Visakhapatnam (Vizagapatam). The deposits at Visakhapatnam have been studied more than the others.

At Visakhapatnam the bedrock in the hills adjacent to the coast is composed of garnetiferous sillimanite gneiss and quartzite of the khondalites, charnockites, leptynites, and also of pegmatite. Overlying these rocks is red loam (Mahadevan and Sathapathi, 1948; Rao and Chetty, 1955, p. 493). Short streams that are rich in black sand lead from the hills to the coast. Monazite on the beaches is invariably associated with ilmenite and magnetite, and, according to the pioneering studies of Mahadevan and Sathapathi, is derived principally from pegmatites in sillimanite gneisses. Anjaneyulu (1953, p. 95) noted that these gneisses are an important source of monazite and showed that the proportion of monazite in the beach sand increases as the abundance of magnetite, ilmenite, and zircon increases (table 19).

South of Visakhapatnam the beaches have been studied to the vicinity of Pudimadaka (Anjaneyulu, 1953, p. 89–94). They range in width from 50 to

TABLE 19.—*Mineralogical composition, in percent, of black sands from streams, dunes, and beaches between Errada and Pudimadaka, India*

[Modified from Anjaneyulu (1953, p. 96)]

	1	2	3	4	5	6	7	8	9	10
Heavy minerals------percent-----	73. 88	63. 57	27. 79	50. 83	67. 68	70. 07	72. 38	68. 04	38. 15	21. 28
Magnetite	51. 62	42. 26	17. 17	31. 86	20. 32	50. 67	50. 02	49. 23	20. 52	7. 56
Ilmenite	7. 03	8. 16	4. 33	6. 49	7. 12	7. 48	4. 27	8. 65	7. 77	3. 85
Garnet	8. 40	4. 79	2. 72	8. 62	35. 40	5. 00	1. 83	4. 17	3. 02	7. 37
Monazite	2. 03	1. 40	. 36	. 67	. 27	1. 12	. 09	. 33	. 57	. 09
Zircon	2. 16	2. 60	. 55	. 84	. 42	1. 79	. 79	1. 48	1. 17	. 13
Rutile	. 69	. 96	. 13	. 48	. 37	. 91	. 67	. 21	. 65	. 07
Sillimanite	. 47	2. 28	. 93	. 75	. 11	1. 35	8. 74	. 24	. 92	. 23
Hypersthene	. 19	. 15	. 47	. 17	. 85	. 15	5. 62	2. 90	1. 91	. 16
Hornblende	. 28	. 55	. 56	. 23	. 30	. 47	. 08	. 16	1. 16	. 13
Kyanite	. 10	. 33	. 02	. 04	. 27	. 28	. 06	. 07	. 03	. 01
Tourmaline	. 12	. 04	. 04	. 13	. 33	. 16	--------	. 03	. 03	. 03

1. Stream near Errada.
2. Beach near Gangavaram at Valametta.
3. Beach near Kutukonda.
4. Beach near Uppeteru.
5. Beach 1 mile southwest of Vadamutupalem.
6. Beach 0.5 mile northeast of Pudimadaka.
7. Stream near Kothuru.
8. Stream near Lemarti Agraharam.
9. Sand dune near Turkhodapalem.
10. Stream near Konavanipalem.

250 feet, are locally steep, and are interrupted by rocky promontories which reach to the sea. Swamps and salt pans are present along parts of the beaches near Gangavaram and Valametta. Formation of black-sand streaks along the beaches depends on several factors including proximity of streams, gradient of the beach, wave activity, and currents. Most black sand is deposited where the largest number of small streams emerge from the hills and where the beaches are flattest and widest. In the area south of Visakhapatnam, monazite constitutes only about 1 or 2 percent of the black sand, which is only about one-fourth of the tenor north of Visakhapatnam. Tonnage of monazite and other minerals in the black sand at Gangavaram and Pudimadaka was estimated by Anjaneyulu (1953, p. 97) to be as follows:

	Tons
Monazite	1, 200
Zircon	1, 250
Ilmenite	4, 200
Garnet	5, 300
Magnetite	27, 000

Beaches north of Visakhapatnam have more extensive black-sand deposits than those south of the town (Mahadevan and Rao, 1950, p. 48). Individual layers of black sand reach a maximum area of 500 by 100 feet and a maximum thickness of 8 inches. Because of changes in the configuration of the beaches, there is a constant redistribution of the concentrates. Placers along the beach between Kailasa and Bhimilapatam are estimated to contain the following tonnage of the minerals given to a depth 5 feet below the surface (Mahadevan and Rao, 1950, p. 49):

	Tons
Monazite	3, 100
Zircon	550
Ilmenite	5, 700
Garnet	12, 500
Magnetite	37, 000

Annually, during the monsoon months, a considerable amount of black sand is sorted, graded, and deposited on the beaches. Black sands are thought to extend to much greater depths than the 5 foot depth used for the estimate of the reserves, but maximum depths were not reported.

The amount of thorium oxide in monazite from Madras and Andhra Pradesh was said (Wadia, 1956, p. 164; Canadian Mining Jour., 1955) to be between 5 and 11 percent.

ORISSA

Monazite was apparently first found on the coast of the Bay of Bengal in Orissa at Satbhaya (Satvaya) in the Cuttack district. In 1924 the deposits were examined and found to extend for 23 miles along the coast (Mining Jour., 1925a; 1947b; Petar, 1935, p. 16). The deposits have an average width of 70 feet and an average thickness of 10 inches. Black sand from the placers consists of 75 percent of ilmenite and a little garnet; the rest is monazite and other minerals. Richest concentrates have 11 percent of monazite; most concentrates have 2–3 percent of monazite. A monazite separate contained 7.9 percent of ThO_2 and 61 percent of RE_2O_3 (Mining Jour., 1925a). A chemical analysis of nearly colorless to honey-colored monazite from a beach 1.5 miles east-northeast of Satbhaya was performed by the Chemical Research Laboratory at Teddington. Results indicated that the monazite contains 9.43 percent of ThO_2 and 0.239 percent of U_3O_8 (Holmes, 1955, p. 90).

JAPAN

The monazite occurrence at Taijin-zan (Tanokami-yama) in Shiga-ken, initially described by Jimbo (1899, p. 245), is the first of several monazite-bearing pegmatites and granites that have been reported in Japan. All the occurrences are of mineralogical interest only, and at least as late as 1956 no discovery of exploitable monazite had been made.

Placers in areas having monazite-bearing pegmatite and granite, such as the regions near Ishikawa and Suisho-yama in Fukushima-ken and near Naegi in Gifu-ken, seem not to have been mined for monazite, although the history of placer mining for cassiterite in Gifu-ken extends back at least to the seventeenth century (Japan Geol. Survey, 1956).

Raised beach and stream placers have long been mined in Japan for iron. The iron sands are mixtures of ilmenite, titaniferous magnetite, and pyroxenes derived from mafic igneous rocks. Monazite was not reported by Staatz (1947, p. 3–8) even as a minor accessory mineral in the 138 iron sand deposits he described in Japan.

The source of the monazite used to make the few tons of ferrocerium smelted in Japan and Korea during 1944–45 was from Korea (Bardill, 1946, p. 39–45) and Malaya (Fermor, 1950, table 2).

Monazite is one of the few rare-earth-bearing minerals found in Japan (Hoshina, 1926). The relation of the geographic distribution of rare-earth minerals to the regional geology was discussed by Kozu and Watanabe (1926, p. 839–841), and their interpretations, as related to the occurrence of monazite, are summarized before descriptions of specific localities are presented.

The islands of Japan can be classed geologically into southwest and northeast halves, and each half can be divided into two zones. The halves are separated by a transverse lowland filled chiefly by sedimentary rocks of Tertiary age and covered by volcanic rocks. The two zones of each half are called the outer zone on the Pacific side and the inner zone on the west side. In southwest half the outer zone consists mainly of stratified rocks of pre-Tertiary age, and the inner zone consists of extensive granodioritic rocks and only sparse sedimentary deposits. In northeast half the outer zone consists of four diagonal horsts geologically similar to the inner zone of southwest Japan. The inner zone of northeast Japan is made up mainly of sedimentary rocks of Tertiary age and younger volcanic rocks.

As monazite in Japan is associated with pegmatite and granite, it most commonly occurs in the inner zone of southwest Japan and the outer zone of northeast Japan. Monazite has been found in the inner zone of southwest Japan in the following kens: Saga-ken and Fukuoka-ken on Kyūshū and Yamaguchi-ken, Kyoto-ken, Nara-ken, and Shiga-ken on Honshū. In the outer zone of northeast Japan, it has been found in Gifu-ken, Aichi-ken, Yamanashi-ken, Ibaraki-ken, and Fukushima-ken on Honshū.

INNER ZONE OF SOUTHWEST JAPAN

KYŪSHŪ

Pegmatite dikes at Nanzan-mura in Saga-ken contain monazite (Kimura and others, 1935, p. 100).

Tabular dark-greenish-gray crystals of monazite as much as 1 inch across are found in a pegmatite dike at Amagi (Amaki, Ataka, Buzen, Kotoge) in Fukuoka-ken (Ito, 1937, p. 166). Monazite, having a specific gravity of 5.05, from the pegmatite was analyzed and was found to contain the following amount of thorium oxide and a remarkable amount of beryllium oxide:

Analysts: Kimura and Iimori (1936, p. 450; see also Kimura and Imiori, 1937, p. 1140, and Harada, 1948, p. 201)]

	Percent		Percent
Ce_2O_3	22.03	TiO_2	0.00
La_2O_3 (group), Y_2O_3 (group)	38.57	ZrO_2	.00
		CaO	.00
ThO_2	5.53	MgO	.00
UO_3	.44	BeO	1.44
P_2O_5	26.41	Loss on ignition	1.38
SiO_2	3.07		
Al_2O_3	.00	Total	100.39
Fe_2O_3	1.52		

This analysis was reported by Kato (1958, p. 227) under the place name of Kotoge, Fukuoka-ken. The abundance of radium in the monazite from Amagi was reported by Kimura and Nakai (1937, p. 1258) to be $Ra=0.0139\times10^{-7}$.

HONSHŪ

Monazite-bearing pegmatite dikes containing accessory zircon and xenotime are known at Yū and Ishii in Yamaguchi-ken (Kimura and others, 1935, p. 100). Monazite is an accessory mineral in adamellite exposed on Hiei-zan in Kyōto-ken (Kozu and Watanabe, 1926, p. 842).

Monazite from pegmatite at Hase-machi in Nara-ken, a locality also referred to as Kutinokura, Kaminago (Harada, 1948, p. 201), and Kuchinokura (Kato, 1958, p. 227) was reported to have the following composition:

[Analysts: J. Masutomi and T. Higami (in Masutomi, 1944, p. 43)]

	Percent		Percent
Ce_2O_3	27.77	Fe_2O_3	1.33
La_2O_3 (group)	28.15	CaO	.47
Y_2O_3 (group)	3.01	MgO	.08
ThO_2	6.49	H_2O	.64
P_2O_5	29.10		
SiO_2	2.64	Total	100.43
Al_2O_3	.75		

The first crystals to be recognized as monazite in Japan were reddish-brown inclusions in topaz identified by Ogawa (Jimbo, 1899, p. 245; Ogawa, 1903). They came from a pegmatite dike at Taijin-zan (Tanokamiyama) in Shiga-ken (Kozu and Watanabe, 1926, p. 841–842; Iimori and Yoshimura, 1929, p. 30)

OUTER ZONE OF NORTHEAST JAPAN

HONSHŪ

The Ebisu wolframite and arsenic mine at Wada in Gifu-ken contains several monazite-bearing pneumatolytic quartz veins and accompanying greisen (Kato, 1958, p. 225). The sequence of rocks at the Ebisu mine includes sedimentary rocks of Paleozoic age which are intruded by quartz porphyry. These were intruded in Late Cretaceous time by porphyritic granite and biotite granite, which silicified the quartz porphyry. Numerous drusy pegmatites occur in the biotite granite. Cutting across the granite and the quartz porphyry are veins that carry wolframite, scheelite, bismuth minerals, arsenopyrite, and monazite. The monazite, besides occuring in the quartz veins with the ore minerals, also occurs in topaz- and mica-bearing greisen and in the silicified wallrocks. It forms small disseminated yellow to dark-brown grains; crystal faces are rare. A sample of monazite from wolframite concentrates prepared at the mine, presumably from the quartz vein, was analyzed and was shown to have the following composition:

[Analyst: Kato (1958, p. 226)]

	Percent		Percent
Ce_2O_3	24.58	Fe_2O_3	0.48
La_2O_3 (group)	38.51	CaO	.86
ThO_2	4.51	PbO	.026
U_3O_8	.21	Loss on ignition	.91
P_2O_5	26.81		
SiO_2	2.24	Total	99.49
Al_2O_3	.36		

Monazite is associated with thorite, fergusonite, and naegite in pegmatite dikes and cassiterite placers at Naegi in Gifu-ken. The area is underlain by granodiorite, granite, and gneiss which are cut by many small pegmatite dikes and cassiterite veins (Kozu and

Watanabe, 1926, p. 841; Iimori and Yoshimura, 1929, p. 30). The dikes contain rare-earth minerals, garnet, tourmaline, topaz, sapphire, and andalusite. River beds and stream terraces are covered with cassiterite-bearing gravel in which are also found the thorium and rare-earth minerals and garnet plus magnetite, ilmenite, beryl, and chrysoberyl. Alluvial deposits at Naegi are strongly radioactive, and this radioactivity was attributed by Shibata and Kimura (1923a, p. 5) and Shibata (1926, p. 854) to monazite and thorite. A sample consisting of monazite and thorite was separated magnetically from a concentrate and chemically analyzed. Results of the analysis showed that this concentrate contained 8.52 percent of ThO_2. The monazite in this material probably did not contain more than 6 percent of ThO_2:

[Analysts: Shibata and Kimura (1923a, p. 5; see also Shibata, 1926, p. 854)]

	Percent		*Percent*
Ce_2O_3	19.44	TiO_2	Trace
Nd_2O_3 (group)	19.70	ZrO_2	Trace
Dy_2O_3 (group)	3.54	Ta_2O_5	Trace
ThO_2	8.52	Nb_2O_5	Trace
P_2O_5	[1]20.42	H_2O-	0.69
SiO_2	10.81	H_2O+	1.64

[1] 20.24 on two.

Monazite sand from Naegi was reported by Satoyasu Iimori (1929, p. 233) to contain 0.085 percent of U_3O_8 and 2.45×10^{-8} percent of Ra.

Monazite was found in pegmatite dikes in Aichi-ken (Kimura and others, 1935, p. 100), and monazite occurs as inclusions in topaz in pegmatite at Kimpozan (Mt. Kimbu, Kinbuzan) in Yamanashi-ken (Kozu and Watanabe, 1926, p. 841; Iimori and Yoshimura, 1929, p. 30). It was also said by Iimori and Yoshimura to be present in pegmatite at Kuropira in Yamanashi-ken. This locality may be the same as Kurobei-yama, a mountain near Kimpo-zan. Pegmatite at Makabe in Ibaraki-ken contains monazite (Kimura and others, 1931, p. 212–213).

The famous pegmatite district at Ishikawa in Fukushima-ken is a source for specimens of monazite, xenotime, samarskite, ishikawaite, zircon, columbite, and beryl (Kozu and Watanabe, 1926, p. 841; Iimori and Yoshimura, 1929, p. 30; Sato, 1926, p. 865; Sakurai, 1941). Many pegmatite dikes intrude a virtually granodioritic terrane. Quartz, perthite, and mica occur as large crystals at some places in the dikes, and they are commonly accompanied by noteworthy crystals of tourmaline, garnet, and andalusite, as well as the rare minerals previously listed. Most of these minerals also occur as detrital grains in streams draining the area.

The monazite from Ishikawa was reported to form very perfect translucent brownish-yellow crystals. Selected crystals of monazite taken from a stream beside Ishikawa-yama were analyzed and found to have specific gravities of 5.17 and 5.195 and the following composition:

[Analysts: *A*, Shibata and Kimura (1923b, p. 14–15; see also, Shibata, 1926, p. 857); *B*, Ueda (1953, p. 228)]

	Percent *A*	Percent *B*
Ce_2O_3	21.08	55.41 (combined Ce_2O_3, $(La, Nd)_2O_3$, Y_2O_3)
$(La, Nd)_2O_3$	31.27	
Y_2O_3 (group)	3.53	
ThO_2	11.08	11.73
UO_3	.42	No data
P_2O_5	27.52	26.69
SiO_2	2.98	2.73
Al_2O_3	.80	.09
Fe_2O_3	.66	1.49
CaO	.52	1.11
MgO	.27	--------
H_2O	.56	[1].20
Total	100.69	99.45

[1] 0.05 H_2O+ and 0.15 H_2O-.

Variation in Ce_2O_3 content from 21.08 percent to 24.14 percent was noted by Shibata and Kimura in samples of monazite from Ishikawa. The samples were said to contain some ZrO_2, TiO_2, and SnO_2 and to display considerable variation in ThO_2 and SiO_2 content (Shibata and Kimura, 1923b, p. 16):

	Percent			
ThO_2	11.08	8.18	7.80	11.55
SiO_2	2.98	1.56	1.82	3.00

The following determinations of thorium, uranium, and radium in monazite from Ishikawa were made by Satoyasu Iimori (1929, p. 230, 232):

	Percent
ThO_2	9.48
U_3O_8	.70
Ra (mean of 3 samples)	20.21×10^{-8}

Monazite from Ishikawa contains 0.0027 percent of He (Sasaki, 1926, p. 254).

Where monazite is sparse in the pegmatites at Ishikawa, a little allanite is found, but where monazite is common, allanite is very sparse (Kimura, 1925, p. 79). The abundance of thorium oxide in allanite from monazite-bearing and monazite-free pegmatites in Japan is about equal, but allanite from monazite-bearing pegmatites contains only about half as much of the rare earths as allanite from monazite-free pegmatites (Minami, 1929, p. 3).

KOREA

The Korean Peninsula is underlain by Upper Cretaceous batholiths of biotite granite, biotite-muscovite granite, and porphyritic granite. Remnants of schist, gneiss, and sedimentary rocks form large roof pendants in the granite. Post-Cretaceous deposits of small areal extent fringe the peninsula. Monazite and xenotime are common minor accessory minerals in the Cretaceous granite and associated pegmatite dikes, in the gneiss and schist and in pegmatite related to the gneiss, and in the unconsolidated debris eroded from these rocks. Scarcely any stream in Korea that crosses the plutonic rocks lacks monazite, and beaches at the mouths of many streams on the east and west coasts are monazite bearing (Gallagher and others, 1946, p. 543–545). Sediments from the Korean coast of the Yellow Sea are more radioactive than sediments from other parts of the coast (Niino and Emery, 1961, p. 753).

No primary monazite deposits of economic grade have been discovered in Korea. The commercial deposits are restricted to stream placers where monazite can be recovered alone or with gold and other minerals such as zircon, fergusonite, samarskite, euxenite, columbite, tantalite, and yttro-tantalite. Prior to 1942, no attention was paid to these minerals, although they are by no means scarce in some of the best gold-dredging ground in Korea. Between 1942 and 1945 some of the deposits were examined, and at a few placers a small amount of monazite was mined by hand methods. A monazite poll tax of 60 pounds of concentrate per year was said to have been imposed on the inhabitants of parts of Korea north of lat. 38° N. during the Russian occupation after World War II (Davidson, 1956a, p. 204). A revival of commercial interest in monazite during the late 1940's and the 1950's in the Republic of Korea led to an output reported to have exceeded a rate of 100 short tons a month in 1956 (Tong, 1956, p. 176), but this monthly rate was apparently maintained for only a short time because the production during 1956 was said to have been only 203 short tons (J. G. Parker, written commun., 1962). The following output was reported as concentrates containing 45–55 percent of RE_2O_3 and also reported as containing 30 percent of Ce which may be high.

	Short tons		*Short tons*
1952	903	1957	392
1953	845	1958	355
1954	1,108	1959	65
1955	560	1960	11
1956	203	1961	854

A published record (Parker, J. G., 1962, p. 1029) listed the output of monazite for Korea in 1961 as 28 short tons, but J. G. Parker (written commun., 1962) subsequently stated that monazite production in 1961 reached 854 short tons. Korean resources in monazite seem to be capable of substantial development.

The distribution of monazite deposits in the Republic of Korea has been reviewed by Gallagher, Klepper, Overstreet, and Sample (1946, p. 546–576) and Tong (1956, p. 177), but the localities they describe, which are summarized in the following discussion, are only a few of the many places where the mineral may be found. It is evident from the literature that monazite is common throughout the country (Kim and others, 1958, p. 169–170; Lee and others, 1956, p. 49; Iimori, 1942, p. 410; Tsuda, 1941, p. 322–325; Iimori and others, 1935a, p. 879). In the following review the deposits are described by province from south to north.

CHŎLLA-NAMDO

Five monazite placers in Cholla-namdo were examined by the Korean Geological Survey and were estimated to contain about 70,000 short tons of monazite (table 20).

The Songjŏng-ni part of the Kwangju monazite placer area consists of streams north and west of the village in a part of Songjŏng-ŭp underlain by granite and gneiss intruded by rare porphyrite veins. In the Changp'yŏng part of the Kwangju placer area, the streams drain granite and a little syenite exposed west of Changp'yŏng and porphyrite dikes east of town. The easternmost headwater tributaries of the monazite-bearing streams in the Tamyang area drain quartz-mica schist and cholrite schist and the southeasternmost streams drain conglomerate of Mesozoic age (Son and Won, 1959, p. 116), but the main burden of the streams comes from granite. The Posŏng-gun and Changhŭng-gun placers occupy valleys of streams draining an area of granite gneiss, porphyrite, and syenite locally overlain by shale. High-grade occurrences of monazite are in some valleys in the porphyrite, syenite, or shale downstream from the gneiss. Streams draining only shale have no monazite placers (Kim and others, 1958, p. 169–170, figs. 4–7). Heavy minerals from weathered samples of granite and granite gneiss in the Tamyang area show that these rocks contain from 0.0001 to 0.009 percent of monazite (Son and Won, 1959, p. 116). Kurye-gun gold placers are monazite bearing (Tong, 1956, p. 177).

CHŎLLA-PUKTO

The Province of Chŏlla-pukto includes monazite placers in the Kumje-gun alluvial gold zone and deposits in Iksan-gun and Muju-gun (Tong, 1956, p. 177; Gallagher and others, 1946, p. 546–576; Iimori and others, 1935a, p. 879). The Kumje-gun alluvial

TABLE 20.—*Size and tenor of selected monazite placers in Chŏlla-namdo, Ch'ungch'ŏng-pukto, and Kyŏnggi-do, Korea*

[Modified from Kim, Hwang, and Sang (1958, p. 169–170)]

Placer	Area (thousands of sq yds)	Depth (feet)	Volume (thousands of cu yds)	Tenor: Percent, Raw sand	Tenor: Percent, Concentrate	Tenor: Pounds per cubic yard	Resources of monazite (short tons)
Chŏlla-namdo:							
Songjŏng-ni	3,389	15.7	23,000	0.049	21.1	1.6	17,800
	10,570	5.2	18,500	.127	43.8	3.6	33,500
Changp'yŏng	2,440	7.2	5,800	.061	34.5	1.7	5,100
	120	6.9	270	.055	44.0	1.6	220
	240	8.8	700	.079	42.0	2.4	860
Tamyang	5,500	8.5	15,600	.051	15.3	1.6	12,200
	120	6.6	260	.068	19.6	2.1	280
Posŏng-gun	380	8.2	1,000	.038	24.0	1.2	600
	104	5.2	180	.081	28.0	2.1	190
Changhŭng-gun	12	1.6	6	.057	33.5	1.7	5
	9	3.3	10	.051	34.0	1.6	8
Ch'ungch'ŏng-pukto:							
Munbaek-myŏn, Chinch'ŏn-gun	860	6.6	1,880	.045	15.0	1.2	1,100
	14	3.6	17	.047	35.0	1.4	12
	39	3.9	50	.039	27.0	1.2	30
	14	3.9	20	.053	25.4	1.6	15
	1	4.3	2	.072	15.0	2.2	2
	4	2.9	5	.037	13.0	1.2	3
Kyŏnggi-do:							
Chŏnghowon-ŭp	3,600	9.8	11,800	.052	16.9	1.6	9,200
	1,970	13.8	9,000	.046	15.1	1.3	5,900
	----------	7.5	----------	.026	22.5	.8	----------
	1,540	3.9	2,000	.120	18.8	3.6	3,600
	----------	7.5	----------	.011	5.6	.3	----------

gold zone consists of placers in Kŭmsan-myŏn of which the best known is the Kumje Ch'aegum near Songke-ri where gold is accompanied by monazite, zircon, samarskite, columbite, and fergunsonite. A concentrate consisting of 90 percent of monazite from the Pongsa-ri area of Hari-myŏn in Kŭmje-gun contained 6.7 percent of ThO_2 (Iimori, Satoyasu, 1942, p. 410). Recalculated to 100 percent, the monazite would contain 7.3 percent of ThO_2.

Two-mica granite in the vicinity of Chŏng-ŭp has from 0.0001 to 0.0287 percent of monazite as an accessory mineral. Its average abundance is 0.0018 percent (Son and Won, 1959, p. 116).

An eluvial placer in Kummā-myŏn (Kumna-myŏn) and Wanggung-myŏn, Iksan-gun, has 2–15 percent of monazite mixed with magnetite, martite, ilmenite, and zircon.

In Chŏksang-myŏn, Muju-gun, monazite is in columbite-bearing pegmatites and associated placers.

CH'UNGCH'ŎNG-NAMDO

Ch'ungch'ong-namdo includes the Ch'onan alluvial zone mentioned by Tong (1956, p. 177) where monazite is associated with columbite, tantalite, fergusonite, samarskite, xenotime, zircon, wolframite, rutile, ilmenite, spinel, magnetite, sillimanite, corundum, garnet, and gold. Gold placers in Ch'onan-gun are among the largest in Korea and of these the Songhwan placer in Ipchang-myŏn (Iimori and others, 1935a, p. 879) and the Chiksan placer (Iimori and Yoshimura, 1929, p. 30) in Chiksan-myŏn probably are the best sources of monazite. Other monazite deposits in Ch'onan-gun include the Sungnam fergusonite and gold placer, gold placers in Ipchang-myŏn along the Ipchang-ch'ŏn to its junction with the Ansong-ch'ŏn, the Sinhung placer in Paebang-myŏn, the Sanjijang placer in Susin-myŏn, and prospects for monazite, zircon, ilmenite, and garnet in Tong-myŏn. The placers are formed in broad valleys on granite and granite gneiss locally intruded by porphyry. The monazite often occurs in elongate, subhedral or broken euhedral grains (Hwang and Park, 1956, p. 116, 121–122).

Several analyses are available for monazite from the Ch'onan placer district. A complete analysis on material from Chiksan placer shows the following amount of ThO_2 but seems to be of an impure concentrate because it contains rather large amounts of SiO_2, $(Nb, Ta)_2O_5$, and ZrO_2:

[Analyst: Shibata (1926, p. 864)]

	Percent		*Percent*
Ce_2O_3	24.69	TiO_2	0.19
Nd_2O_3 (group)	31.16	ZrO_2	1.05
Y_2O_3 (group)	2.31	$(Nb, Ta)_2O_5$	1.50
ThO_2	5.47	CaO	.53
P_2O_5	25.89	Loss on ignition	.68
SiO_2	4.08		
Al_2O_3	1.36	Total	100.26
Fe_2O_3	1.35		

Various samples of monazite from Chiksan placer were reported by Satoyasu Iimori (1929, p. 230, 233) to contain 6.91, 6.46, and 6.33 percent of ThO_2, 0.582 percent of U_3O_8, and 16.80×10^{-8} percent of Ra. Sasaki (1926, p. 254) found that monazite from Chiksan placer had 0.0017 percent of He.

Monazite from placers in Ipchang-myŏn, Ch'onan-gun, was said by Satoyasu Iimori (1942, p. 410) to contain 6.9 percent of ThO_2 and by Hwang and Park (1956, p. 116) to contain 7.08 percent of ThO_2, 60.14 percent of the RE_2O_3 and 0.50 percent of U_3O_8. Monazite from the Sungnam fergusonite and gold placer contains an average of 5.3 and ranges from 5.1 to 5.5 percent of ThO_2 and contains 0.71 percent of U_3O_8 (Yoon and others, 1956, p. 74).

Placer operations in 1944 along the valley of the Kŭm-gang and its tributaries in Puyŏ-myŏn, Puyŏ-gun, and adjacent areas of Nonsan-gun were reported (Gallagher and others, 1946, p. 558) to have recovered 2,200 short tons of concentrate consisting of monazite and zircon. The Choson placer in Ungch'on-myŏn, Poryŏng-gun, produced 17.5 short tons of zircon and monazite in 1944. Other deposits are known at Taech'on-myŏn and Ch'ŏngna-myŏn in the same general area.

Monazite of unknown source in Hongbuk-myŏn, Hongsong-gun, was reported to contain 4.8 percent of ThO_2 (Iimori, Satoyasu, 1942, p. 410).

A beach placer in Soch'on-gun extending from So-myŏn eastward along the Yellow Sea into Piin-myŏn was the source of 57 short tons of monazite concentrate in 1944.

The alluvium in the Haki-ri placer in T'andong-myŏn, Taedŏk-gun, has from 0.8 to 1.0 percent of heavy minerals in quartz sand and gravel. The coarsest fragments in the gravel are about 3 inches in diameter. In the raw sand the heavy minerals average about 0.14 percent of monazite, 0.39 percent of magnetite and ilmenite, 0.12 percent of garnet, and 0.1 percent of zircon. Inasmuch as only 4.5 percent of the monazite is as large as −45 mesh and 50 percent of the raw sand coarser than −35 mesh, at least half of the raw sand can be removed with little loss in monazite. In 1957 the deposit was being worked by simple hand methods (Roe and An, 1958, p. 36).

The Chŏnŭi placer in valleys north of Chŏnŭi in Chŏnŭi-myŏn, Yon-gi-gun (Yongi-gun), was mined in a small way in 1946 for fergusonite. Monazite and gold were among the heavy minerals recovered. Placers along the Miho-ch'ŏn, Chak-ch'ŏn, and Cho-ch'ŏn in the vicinity of Choch'iwŏn in Yongi-gun produced 11 short tons of monazite concentrate in 1944. The concentrate included zircon and possibly some scheelite.

CH'UNGCH'ŎNG-PUKTO

Monazite in Ch'ungch'ŏng-pukto is concentrated with zircon, magnetite, titanite, pyroxene, and hornblende in the sediment of the Changp'yŏng-ch'ŏn in Pongyang-myŏn, Chech'ŏn-gun and in the Ch'ongwon-gun placer mineral zone in Oksan-myŏn, Och'ang-myŏn, and Puyong-myŏn where it is associated with zircon (Tong, 1956, p. 177; Gallagher and others, 1946, p. 556). It has been found in Koesan-gun. The Munbaek-myŏn placer in Chinch'ŏn-gun is formed in small streams draining granite gneiss and was reported (table 20) to have a reserve of about 1,200 short tons of monazite (Kim and others, 1958, p. 169–170).

KYŎNGSANG-NAMDO AND KYŎNGSANG-PUKTO

A concentrate containing 80 percent of monazite from Hadong-up, Hadong-gun, Kyŏngsang-namdo, was said to contain 3.7 percent of ThO_2 (Iimori, Satoyasu, 1942, p. 410). If calculated to pure monazite, the tenor in ThO_2 becomes 4.6 percent. The geologic occurrence is unknown.

In Kyŏngsang-pukto 19 alluvial placers having 2–14 percent of monazite in the heavy minerals are known in a region including parts of Yonggung-myon, Kaep'o-myŏn, Kamch'ŏn-myŏn, Yech'ŏn-ŭp, Yong-mun-myŏn, Yuch'ŏn-myŏn, and Sanbuk-myŏn in Yech'ŏn-gun and Mun'gyong-gun. At the P'unggi placer in P'unggi-myŏn, Yongju-gun, 1,598 short tons of concentrate containing 4–5 percent of monazite was recovered between 1942 and August 1945 by panning garnet-rich layers in alluvial sand. These layers make up less than 1 percent of the sediments in a flood plain that is 10 miles long and 0.5 mile wide.

KANGWŎN-DO

Monazite-bearing beach placers extend intermittently northward from Chumunjin, Kangnŭng-gun, to Kŏsŏng-gun along the shore of the Japan Sea to form the Kŏsŏng coastal placer area (Tong, 1956, p. 177; Yoon and others, 1958, p. 189). Originally the deposits were known as ilmenite placers, but investigations in 1956–58 disclosed detrital monazite and zircon. Sand from Hwajin-p'o in the Kŏsŏng placer district contains about 10 percent of heavy minerals consisting of 3.5 percent of ilmenite, 0.2 percent of monazite, 0.2 percent of magnetite, 0.6 percent of zircon, 3.2 percent of garnet, and 2.7 percent of epidote (Roe and others, 1958, p. 38). The area where the placers have formed consists mainly of mica schist and injection gneiss of Precambrian age intruded by granite of Cretaceous age.

Placers occur on the beaches, in river-mouth bars, and bay-mouth bars. Particularly well-defined deposits have been found north of Oho-ri and around Konghyŏnji-ri in Chukwang-myŏn, Yangyang-gun. They also occur between Kajin-ni and Panam-ni in Kansŏng-myŏn, at Kojin-ni in Kojim-myŏn, between Changpyŏng-ni and Chŏdo-ri, from Chŏdo-ri to Chaltong-ni, and along the shore south of Musongjong in Hyŏnnae-myŏn, Kŏsŏng-gun. Concentrates from the placer district were reported to contain 4.24 percent of ThO_2 in mixtures having unreported abundances of monazite (Yoon and others, 1958, p. 200). The monazite was said to have 6.9 percent of ThO_2 (Iimori, Satoyasu, 1942, p. 410). At least 1,600 short tons of monazite were estimated to be in the placers in the district (Yoon and others, 1958, p. 206). Monazite and zircon occur in stream placers in Hyŏnnam-myŏn, Yangyang-gun.

KYŎNGGI-DO AND HWANGHAE-DO

Near Seoul in the province of Kyŏnggi-do, monazite occurs with zircon in placers in Sŏ-ŭn-myŏn of Ansong-gun. Monazite is associated with zircon, spinel, garnet, and magnetite in residual and alluvial deposits near the confluence of the Pokha-ch'ŏn and Han-ch'ŏn in Paeksa-myŏn, Sindun-myŏn, and Ich'on-ŭp of Ich'ŏn-gun. A large placer south of Chŏnghowon in Chŏnghowon-ŭp, Ich'ŏn-gun, is in a valley which in part continues northward along the contact between granite on the west and granite gneiss and mica schist on the east (Kim and others, 1958, fig. 9). The placer contains 18,700 short tons of monazite.

Monazite from a deposit in Chinbong-myŏn, Kaesŏng-gun, contains 5.5 percent of ThO_2 (Iimori, Satoyasu, 1942, p. 410).

The Kwangu Paeknyon gold placer along the Sutnae-ch'ŏn in Chungdae-myŏn and Kuch'ŏn-myŏn, Kwangju-gun, contains monazite and zircon. Traces of monazite and zircon are in concentrates at the site of former gold dredging in Wŏnsam-myŏn, Yong-in-gun.

An alluvial placer extends about a mile down the Ansŏng-ch'ŏn in Songt'an-myŏn, P'yŏngt'aek-gun, from the town of P'yŏngt'aek to tidewater. In 1944 the placer produced 45 short tons of sand which contained 70 percent monazite and zircon.

Off the coast of Kyŏnggi-do, monazite occurs on the islands of Yongyu-do in Yonghŏng-myŏn, Puch'ŏn-gun, and Kanghwa-do in Sŏnwŏn-myŏn, Kanghwa-gun. The deposit on Kanghwa-do, known as the Il Pung gold placer, yields black sand composed dominantly of ilmenite and columbite or tantalite, corundum, 30 percent of monazite, and less than 1 percent of red garnet and zircon.

North of Seoul in the province of Hwanghae-do, the Kukum gold placer in Haewŏl-myŏn, Yŏnbaek-gun, may be the finest fergusonite deposit in Korea (Gallagher and others, 1946, p. 575). Concentrates from the placer have the following composition:

	Percent
Monazite	>12
Zircon	10±
Garnet	<5
Scheelite	[1] 4.8
Ilmenite and rutile	60±
Magnetite	<2
Fergusonite	[2] 7–27
Columbite	5–12

[1] >14-in. mesh.
[2] >28-in. mesh.

Monazite from Haewŏl-myŏn, probably from the Kukum placer, was reported to have 11.0 percent of ThO_2, a composition which makes it the most thorium oxide-rich monazite in Korea (Iimori, Satoyasu, 1942, p. 410).

P'YŎNGAN-NAMDO AND P'YŎNGAN-PAKTO

Monazite was recognized as early as 1919 as one of the minerals in the Sun-an gold placer in Tongam-myŏn, Pyongwon-gun (Koto, 1919). A complete analysis of monazite from the Sun-an placer follows:

[Analysts: Kimura and Shinoda (1931, p. 50)]

	Percent		Percent
Ce_2O_3	28.25	SnO_2	0.15
Nd_2O_3	27.87	CaO	.53
Y_2O_3	2.47	PbO	.09
ThO_2	9.49	Sb_2O_5	.06
UO_3	.15	CO_2	.23
P_2O_5	26.07	H_2O+	.79
SiO_2	1.85		
Al_2O_3	.28		
Fe_2O_3	1.65	Total	99.93

Partial analyses of monazite from Sun-an have also been published:

	1	2	3	4	5
ThO_2		9.56	9.65	9.62	10.7
U_3O_8		.111		[1] .11	
Radium		3.21×10^{-8}			
Helium	0.0028				

[1] Specific gravity, 5.11.

References:
1. Sasaki (1926, p. 254).
2. Satoyasu Iimori (1929, p. 230).
3. Satoyasu Iimori (1929, p. 233).
4. Tsuda (1941, p. 325).
5. Satoyasu Iimori (1942, p. 410).

The age of this detrital monazite was determined by Satoyasu Iimori (Tsuda, 1941, p. 325) to be 117 million years, which indicates that it was probably derived from the Cretaceous granite or related pegmatite.

The Sun-an placer is part of the Pyongwon-gun placer monazite zone of Tong (1956, p. 177).

Sunch'ŏn-gun is the center of reported occurrences of monazite in placers and pegmatites: Pongch'ang-ni in Pongton-myŏn, Kusang-ni and Chungsang-ni in Pukch'ang-myŏn, Taepyŏng-ni in Unsan-myŏn, and Happ'i-ri in Wŏnt'an-myŏn (Iimori and others, 1935a, p. 879; Lee and others, 1956, p. 49). Analyses of monazite from Pongton-myŏn and Unsan-myŏn show 7.1 and 5.5 percent of ThO_2 (Iimori, Satoyasu, 1942, p. 410).

Concentrates from placers in the Pongch'ang-ni area of Pongtong-myŏn and the Taepyŏng-ni area of Unsan-myŏn were reported to contain from 7 to 12 percent of monazite (Iimori and others, 1935b, p. 354):

	Percent			
	Pongch'ang-ni		Taepyŏng-ni	
Monazite	8.3	12.4	7.0	10.4
Ilmenite	30.5	87.6	19.0	89.6
Other minerals	61.2		74.0	

Monazite has been found at Chajak-ri in Puk-myŏn and in Pongtong-myŏn, Kaech'on-gun (Iimori and others, 1935a, p. 879; Lee and others, 1956, p. 49). It has also been reported from Sin-ni in Yŏngwŏn-myŏn, Yŏngwŏn-gun, P'yŏngan-namdo.

Three analyses of monazite from other localities in P'yŏngan-namdo show 5.1, 6.0, and 6.2 percent of ThO_2 (Iimori, Satoyasu, 1942, p. 410).

Monazite was said to occur in gold placers at Kandong, Sinsu-myŏn, Sonch'ŏn-gun. It has been found in large lumps in Cholsan-gun (Tong, 1956, p. 177). Several other localities in P'yŏngan-pukto were reported to be monazite bearing (Iimori and others, 1935a, p. 879; Lee and others, 1956, p. 49).

HAMGYŎNG-NAMDO AND HAMGYŎNG-PUKTO

Black monazite occurs in heavy concentrates obtained from sand and gravel on bedrock at a depth of 20 feet below the paddies at Inhŭng-myŏn, Yonghŭng-gun, Hamgyŏng-namdo. The following is a complete analysis of this black monazite which had a specific gravity of 5.16:

[Analyst: Takeo Iimori (1941, p. 1052)]

	Percent		*Percent*
Ce_2O_3	25.10	Al_2O_3	0.45
$(La, Nd)_2O_3$ (group)	37.14	Fe_2O_3	.42
Y_2O_3 (group)	1.26	CaO	1.58
ThO_2	5.81	MgO	.00
UO_3	.66	BeO	.00
P_2O_5	27.55		
SiO_2	.93	Total	100.90

Monazite from the same locality has also been reported to contain 6.6 percent of ThO_2 (Iimori, Satoyasu, 1942, p. 410).

Monazite was reported to occur with rutile in placers in the province of Hamgyŏng-pukto at Sangjin-dong, Kwanhae-myŏn, Puryŏng-gun (Lee and others, 1956, p. 49).

PAKISTAN

A concentrate from the Indus River at Amb, Hazara District, West Pakistan, contains abundant magnetite and lesser quantities of ilmenite, zircon, monazite, garnet, uraninite, uranothorite, amphibole, and scheelite (Danilchik and Tahirkheli, 1959, p. 5). Spectrographic analysis of a concentrate from cobble gravel in the Hunza River at a point 0.5 mile above its confluence with the Gilgit River showed thorium and the rare earths in abundances interpreted by Danilchik and Tahirkheli to indicate monazite in the alluvium. At both localities the main source of the detrital minerals is granodiorite and metamorphosed mafic volcanic rocks. As late as 1959 no economic deposits of placer monazite had been found in West Pakistan.

Beach placers containing monazite were reported from 10 localities along the east coast of the Bay of Bengal, East Pakistan, extending from Chittagong to the Burmese border (Schmidt and Asad, 1962).

The placers, generally containing 10–30 percent heavy minerals, are on the ocean beach and in the foredunes. Each placer is tens or hundreds of feet wide and several hundreds to thousands of feet long; one extends for several miles. Local lenses that contain as much as 96 percent minerals of specific gravity exceeding 2.80 were found at several localities within the placers. A reconnaissance study of one of these placers indicated provisional reserves of 487,000 short tons of sand containing 10 percent heavy minerals, 163,000 short tons of sand containing 20 percent heavy minerals, and 6,300 short tons of sand containing 30 percent heavy minerals (Schmidt and Asad, 1963). Monazite percentages were not estimated, and no attempt has been made to exploit these placers.

Magnetite makes up 8 percent of the heavy minerals in the main placers, which contain 10–30 percent heavy minerals, but about 50 percent of the heavy minerals in the lenses that consist almost entirely of heavy minerals. The main placer at Cox's Bazar contains the following heavy-mineral suite:

Abundant	*Common*	*Sparse*
Magnetite	Tourmaline	Amphibole
Pyroxene	Staurolite	Kyanite
Ilmenite(?)	Zircon	Muscovite
Epidote	Rutile	Biotite
Garnet		Monazite

The monazite in the Cox's Bazar placer is pale yellow, yellowish gray, brownish yellow, and whitish yellow in samples examined by the author.

PHILIPPINES

Seventeen samples of sand from streams and beaches in the Philippines were determined by Bacon (1910, p. 277–278) to be radioactive. Very radioactive black sand from Nueva Ecija contained magnetite, zircon, gold, platinum, monazite, and probably iridium. Black sand near Paracale, Ambos Camarines, Luzon, contained very radioactive monazite. The localities of the 15 other radioactive samples of sand were not given.

REPUBLIC OF INDONESIA

Monazite is found in the alluvial tin placers on the islands of Belitung, Bangka, and Singkep between Sumatra and Borneo (Gisolf, 1926, p. 1729). It probably occurs with cassiterite in placers on the Kepulaun Riau off the tip of Malaya along the trend of the monazite-bearing tin and tungsten placers that have been mined as far north as Burma (Bemmelen, 1949, p. 92, 95). Monazite is in stream placers near Bengara, Kalimantan (West Borneo), and has been found on the beaches of Kalimantan and northern and western Sumatra.

On the three main "tin islands" of Belitung (Billiton Island), Pulau Bangka (Banka Island), and Pulau Singkep (Singkep Island), monazite is associated with cassiterite. A placer on Pulau Bangka was said to have contained too much monazite to permit profitable recovery of the cassiterite (Davidson, 1956a, p. 203–204), but there is no record that the monazite was shipped from the island. Five tons of monazite was mined at Belitung in 1896, and an unrecorded amount was produced in 1909 (Davidson, 1956a, p. 203). Small but unreported amounts of monazite were shipped from Pulau Singkep in 1894, 1895, and 1896. Most of the recorded production of Indonesia has been from the tin placers on Pulau Singkep. Between 1936 and 1939 the output of monazite was 1,713 short tons (Nederlandsch-Indië, Dienst van den Mijnbouw, 1938; Economic Weekblad voor Nederlandsch-Indië, 1940, p. 739; Bemmelen, 1941, p. 16; 1949, p. 146; Stauffer, 1945, p. 332):

	Short tons
1936	736
1937	408
1938	433
1939	136
Total	1,713

Varying amounts of monazite were produced in the 1950's and early 1960's (Crawford, 1957a, p. 6; J. G. Parker, written commun., 1962):

	Short tons
1953	314
1954	11
1955	122
1956	Not available
1957	Not available
1958	Not available
1960	Not available
1961	111

The position of Pulau Singkep as the leading producer of monazite in Indonesia may be due to the greater amount of thorium oxide in monazite from that island in contrast to thorium oxide-free and hence commercially unacceptable monazite from Belitung. Placer monazite from Pulau Singkep was reported to contain 3.27 and 3.4 percent of ThO_2 (Davidson, 1956a, p. 204).

Two analyses of detrital monazite from a tin placer near Dendang on Belitung follow:

[Analyst: C. Winkler (in Hintze, 1922, p. 342, 370)]

	Percent	
	A	*B*
Ce_2O_3	56.79	60.54
$(La, Nd, Pr)_2O_3$	8.60	6.86
Y_2O_3	2.29	1.08
ThO_2	.00	.00
P_2O_5	29.76	29.37
SiO_2	.91	1.44
Fe_2O_3	.22	Trace
NiO	.50	-------
SnO_2	Trace	-------
Loss on ignition	.59	.39
Total	99.66	99.68

A. Specific gravity, 4.92.
B. Specific gravity, 4.94.

These analyses showed no thorium oxide, and in this respect the monazite resembles thorium-free monazite from tin veins at Cerro de Llallagua, Bolivia (Gordon, 1944, p. 330).

The bedrock source of the monazite in the Dendang placer is not known. The monazite may have come from cassiterite-bearing granite east of Dendang, or from greisen and cassiterite-bearing quartz veins in the granite, or from contact zones and cassiterite-bearing quartz veins in the feebly metamorphosed sandstone into which the granite is intruded (Bemmelen, 1949, p. 96, 99–101). The sandstone is not likely to have been the source.

Minerals associated with detrital monazite in the cassiterite placers on Belitung, Pulau Bangka, and Pulau Singkep are xenotime, ilmenite, pyrite, marcasite, hematite, rutile, allanite, zircon, and tourmaline.

The cassiterite granites of Pulau Bangka contain allanite, zircon, and apatite, but monazite has not been observed in them, although it is in concentrates from the placers. Monazite was found in granite, biotite gneiss, and biotite schist on Pulau Berhala in the Strait of Malacca (Westerveld, 1936, p. 1123–1124). Monazite was found along the north and west coasts of Sumatra, but the exact localities were not reported (Van Wickel and George, 1924, p. 544; Chem. Trade Jour. and Chem. Engineer, 1924; Chemische Industrie, 1924).

Several reports in 1924 announced the discovery of monazite in Kalimantan (West Borneo), and one stated that monazite seemed to be present in large quantities, but evidently the reports were somewhat exaggerated (Chem. Trade Jour. and Chem. Engineer, 1924; Metallurgie und Erz, 1924; Chemische Industrie, 1924; Van Wickel and George, 1924, p. 544). Levy introduced a note of confusion into the reports by incorrectly reporting that this monazite contained 9 percent of ThO_2 (Levy, 1924a).

Very fine samples of perfectly crystallized monazite were found in Kalimantan near the border with Sarawak (Gisolf, 1926, p. 1729).

Monazite occurs in gneissic quartz diorite in the migmatitic area in the southeastern part of the Kembajang Mountains of central and eastern Kalimantan (Zeijlmans van Emmichoven, 1939a, p. 50–53, pl. 1; 1939b, p. 194; Roe, 1958, p. 47).

Gneissic granite exposed in the Halilit River in central Kalimantan is intruded by veins of granite pegmatite which contain tourmaline, cassiterite, and monazite (Nederlandsch-Indië, Dienst van den Mÿnbouw, 1935, p. 22).

Five samples of sandstone of Triassic age from northeastern Timor contain a fraction of a percent of monazite (table 21).

TABLE 21.—*Mineralogical composition, in percent, of heavy-mineral fraction, of monazite-bearing concentrates from sandstone of Triassic age in northeastern Timor*

[Modified from analyses by Simons (1939, p. 74–76)]

	1	2	3	4	5
Opaque minerals	67.5	57.0	85.0	77.0	14.5
Tourmaline	4.2	7.5	1.8	3.0	5.5
Zircon	13.0	18.3	3.8	9.9	3.8
Garnet	8.1	10.8	5.1	5.0	65.7
Rutile	3.2	1.5	.9	1.6	2.5
Brookite	------	------	------	------	.4
Anatase	.7	------	.2	.2	.8
Titanite	------	.4	.2	------	.8
Muscovite	1.3	1.5	1.8	1.2	1.2
Epidote	.3	.4	.2	.2	1.6
Hornblende (blue-green)	.7	------	.6	1.2	------
Chromite	.3	1.1	.2	.2	1.6
Monazite	.7	1.5	.2	.5	1.6

1. Graywacke sandstone exposed in the Motta Baoekonoe south of Babkaniem.
2. Graywacke sandstone exposed in the Motta Baoekonoe south-southwest of Weklosoen.
3. Sandstone with calcareous cement exposed near the highest point on the path between Tabean and Woonari.
4. Sandstone with calcareous cement exposed southwest of Weklosoen.
5. Graywacke from the valley of Motta Toebatan about a mile downstream from Toebatan.

SARAWAK AND NORTH BORNEO

SARAWAK

The earliest description in the literature of a natural concentration of monazite sand was made by Hugh Low when he commented upon but did not identify monazite at Lingga (Lingah), Sarawak. Low (1848, p. 29) wrote:

> A beautifully resplendent sand, the particles of which resemble amethysts and topazes, and which is used in the adulteration of gold dust, may perhaps be thought to indicate the vicinity of other gems: it is found at Lingah, a branch of the great Batang Lupar river, not far from its mouth.

Over a hundred years later Haile (1954, p. 103) identified the occurrence as monazite in a stream sand near Gunong Lesong. Gunong Lesong is a spectacular flat-topped mountain composed of microgranite of pre-Tertiary age which is capped by a nearly horizontal layer 500–1,000 feet thick, of sandstone of Tertiary age. Sand from streams on the north and northeast flanks of Gunong Lesong contains small euhedral crystals of monazite, often in considerable abundance, associated with tourmaline, andalusite, zircon, and topaz. The source of the monazite was inferred to be the microgranite, though monazite was not certainly identified in the rock (Haile, 1954, p. 35, 102; Wilford, 1953, p. 33; Haile, 1952, p. 14).

A monazite separate from the Gunong Lesong area, prepared by S. H. U. Bowie of the Atomic Energy Division, Geological Survey of Great Britain, contained 6.8 percent $eThO_2$ (Haile, 1954, p. 102).

Monazite was found by N. S. Haile in 1955 in concentrates from the Sungei Entabai (Entabai), a tributary to the Batang Rajang, and in 1957 was discovered by E. B. Wolfenden in sand near Sibu in the Batang Rajang delta (Roe, 1958, p. 20–21). Although the primary source of the monazite in these localities is unknown, the source is probably granitic and metamorphic rocks in the western part of Sarawak and adjacent parts of Kalimantan. The immediate source of the monazite in the Sungei Entabai is sedimentary rocks. They are probably in part the immediate source for some of the monazite in the delta of the Batang Rajang, but some of the monazite in the delta has probably come directly from the crystalline rocks of the hinterland.

Black marine sand rich in ilmenite and zircon was discovered near the mouth of the Batang Bintulu in 1950 by N. S. Haile (Wilford, 1953, p. 33; Kirk, 1957, p. 57–68; Kirk, 1958, p. 85). Small quantities of monazite, rutile, and garnet are present, and these heavy minerals are accompanied by magnetite, corundum, sillimanite, andalusite, chiastolite, staurolite, tourmaline, brookite, anatase, sphene, and apatite. The sand is banded and the main concentrations are near the high tide mark and extend 2¾ miles along the arcuate coast from Tanjong Batu to Tanjong Kirudong. Backing the beach is a wide coastal plain consisting of Recent alluvial sediments and older alluvial and marine deposits overlying sandstone of Miocene age. Four main types of coastal deposits are present (Kirk, 1957, p. 57–59): (1) modern beach sand, (2) beach sands forming a platform at the back of the present beach and about 7 feet above sea level, (3) raised beach and alluvial deposits which fringe the hills at an altitude of 30 feet above sea level, and (4) Recent alluvial deposits. Recent alluvium is barren of heavy minerals. No concentrations of heavy minerals have been found in the raised beach and alluvial deposits at the 30-foot level, and only a little black sand occurs in the 7-foot platform. The main deposits of banded black sand are in the modern beaches. Only 30,000 tons of sand estimated to contain an average of not less than 5 percent of ilmenite and zircon are in the deposit. Mineralogical analyses disclosed that monazite makes up less than 1 percent of the concentrate. The deposit was regarded as uneconomic in 1957 (Kirk, 1957, p. 57).

The source of the heavy minerals in the deposits between Tanjong Batu and Tanjong Kirundong was thought by Kirk (1957, p. 67) to be crystalline rocks in western Sarawak and parts of Indonesian Borneo. During maximum glaciation the lowering of sea level may have caused regression of the sea from the Sunda Shelf, and rivers whose headwaters were in the crystalline rocks of western Borneo may have deposited their alluvium in the present China Sea adjacent to the Batang Bintulu area. Reworking of these deposits, and longshore drift, may have formed the present deposits (Kirk, 1957, p. 67–68).

That large black sand deposits are present is improbable. At none of the four areas in Sarawak where monazite is known is it sufficiently abundant to be recovered (Roe, 1959, p. 40).

NORTH BORNEO

Deposits of monazite are known in three places in North Borneo, but they are uneconomic owing to their small size and inaccessibility (Collenette, 1956, p. 172; Fitch, 1956, p. 179; Roe, 1957, p. 130). The deposits are at the extreme head of the Sungei Segama (Segama River), somewhat farther downstream on the Sungei Segama where they are associated with placer gold and black sand, and near the mouth of the Sungei Tingkayu (Tingkayu River), which empties into Darvel Bay. The upper parts of Sungei Segama drain intermediate and mafic igneous rocks, and the basin of the Sungei Tingkayu is underlain mainly by sedimentary rocks of Tertiary and Quaternary age (Roe, 1958, p. 128).

THAILAND

Monazite occurs in pegmatite veins and granite gneiss, and in eluvial deposits accumulated therefrom, in western Thailand, but it has yet to be discovered along the beaches in southern Thailand. Its best known occurrence is with cassiterite, tantalite, columbite, ilmenite, and garnet in alluvial tin placers near the west border of the country and in the peninsula between Burma and Malaya. These placers are a northern extension of similar deposits in Malaya.

Tailings from cassiterite placers mined at Thung Kha (Tongkah Harbor) and from those mined by the Kamunting Tin Dredging Co. on the Phang-nga River in Changwat Phang-nga contain monazite. Only a small amount was found at Tongkah Harbor (Anderson, 1924), but reprocessed concentrate from the Phang-nga River contained 70 percent of monazite and 20 percent of tantalite after the ilmenite was removed (Buravas, 1951). An analysis of the reprocessed concentrate showed 4 percent of ThO_2 and 45 percent of RE_2O_3, equal to about 5.7 percent of ThO_2 in the monazite. Monazite from cassiterite tailings at Phang-nga contains about 5.7 percent of ThO_2 (Thailand Delegation, 1956, p. 202).

Very small amounts of marketable monazite concentrates have been produced in Thailand, 18 short tons being reported for 1956, 64 short tons for 1957, and 1 short ton for 1958 (J. G. Parker, written commun., 1962). Output was apparently maintained during 1959–61, but data are not available. When prices justify the reprocessing of black sand waste from tin mining, or the recovery of monazite during mining, then possibly a greater output of monazite can be expected from Thailand.

TIBET

Monazite was detected in a concentrate made from sand in the Brahmaputra (Tsangpo) River near Chaksam in southeastern Tibet (LaTouche, 1918, p. 390).

AUSTRALIA, NEW ZEALAND, AND ANTARCTICA

Small amounts of monazite have been reported from every State in Australia and from New Zealand. Repeated attempts to find commercially acceptable monazite in the tin and tungsten placers in eastern

Australia have failed because much of the monazite in these deposits contains less than 2.0 percent of ThO_2. Low-thorium oxide monazite mined in the early 1900's at the mouth of the Frazer River on King Island between Victoria and Tasmania was not wanted by industry, and the venture failed. An annual byproduct output of as much as several hundred tons of monazite having 6.6 percent of ThO_2 has been maintained since 1948 at the extensive zircon-rutile placers along the southeast coast of Queensland and the northeast coast of New South Wales. It is very likely that beach placers will be discovered elsewhere along the coasts of Australia, particularly in areas where the shore deposits are formed from materials derived from plutonic metamorphic and igneous rocks. The coasts of Western Australia may be especially favorable.

The occurrences in New Zealand are not economic sources of monazite, and the very few in Antarctica are mineralogical curiosities.

AUSTRALIA

NORTHERN TERRITORY

Early reports mentioned several monazite-bearing veins at a place called variously Wolfram Creek (Mining Jour., 1908) and Wolfram Camp (Australian Mining and Eng. Rev., 1909a, 1909b), which may be at or near Wolfram Hill, but more precise locations were not cited. Monazite from one of the veins, presumably a wolframite-bearing quartz vein, contained 1.0 percent of ThO_2 (Australian Mining and Eng. Rev., 1909a).

Monazite is a very scarce mineral in concentrates made from alluvium and stanniferous greisen at Nungado (Baker and Edwards, 1956a). Associated minerals are tourmaline, staurolite, kyanite, epidote, zoisite, muscovite, and rarely hornblende, corundum, and green spinel. The deposit has no economic importance as a source for monazite. Other descriptions of monazite in Northern Territory have not been found, although thorium-bearing deposits of undetermined mineralogy are mentioned by Davidson (1956a).

QUEENSLAND AND NEW SOUTH WALES

Monazite occurs with zircon, rutile, ilmenite, gold, platinum, and osmiridium in beach and dune sands along the coast from the Johnstone River, 50 miles south of Cairns, Queensland, to Batemans Bay, 120 miles south of Sydney, New South Wales. Monazite was first found in the beach sands at Tweed Heads, New South Wales, in 1902 (Dunstan, B., 1905a, p. 11; 1905b) and in the Richmond River district, New South Wales, in 1903 (Mining Jour., 1903a, p. 182). In the late 1800's and early 1900's, the beach sands were intermittently mined for gold, platinum, cassiterite, and monazite (Ball, 1905; Raggatt, 1925, p. 16; Whitworth, 1931, p. 60) but generally failed to be a profitable source for these minerals. Later the coastal deposits were profitably mined for zircon and rutile. Placers on the shore have yielded a large part of the world's commercial zircon and rutile since 1936 and from 1948 have been a source of monazite stockpiled by the Commonwealth Government (Poole, 1939, p. 216–220; Mining Jour., 1941a; Nye and others, 1950, p. 42; Mining Jour., 1954b, p. 130; Blaskett and Hudson, 1955, p. 1; Brown and Dey, 1955, p. 256; Gardner, 1955, p. 9; Australia Dept. Natl. Devel., 1956, p. 92; Hudson, 1957, p. 1–3). Potential monazite output as a byproduct of the rutile mining was estimated by Hudson and Blaskett (1958, p. 161) to be 1,500 tons in 1956, but actual production was only 102 tons of high-grade concentrate owing, apparently, to a lack of separatory equipment.

The littoral monazite placers were reported by Whitworth (1931, p. 59), Beasley (1948; 1950), and Gardner (1955) to be in present beaches, in old beaches buried below sand ridges parallel to the present shore, and in raised heathland or swamps. Rarely, the placers are below the present sea level at the seaward edge of the raised heathland. Large low-grade placers have been discovered in transgressive dunes elongated parallel to the direction of the prevailing wind. During storms from the southeast the surf concentrates heavy minerals along the upper part of the beach where the minerals form wedge-shaped deposits 30–50 feet wide and at the most about 5 feet thick. The deposits extend along the length of the beach and thin out toward the ocean. They are thickest at the ends of beaches that thin northward against natural barriers. In good weather the sand dries and ultimately windblown sand covers the upper parts of the deposits, but the seaward part tends to be washed away unless it, too, is protectively buried. Deposits buried beneath sand ridges along old beaches are similar in appearance to the deposits on the present beaches. Several may be arranged en echelon with white sand between them. The raised heathland and swamps are elevated old beaches, flats, and dunes similar to those along the present coast except that original features have been modified by erosion. The submerged placers at the seaward edge of raised heathlands are formed by the erosion of the raised ground. Large low-grade placers in transgressive dunes are restricted to Stradbroke Island, Queensland, where beach deposits of heavy minerals, previously concentrated by the surf, have been eroded and redistributed by the wind.

The sand along the beaches from Frazer Island, Queensland, southward to Batemans Bay, New South Wales, consists chiefly of quartz and was deposited mainly in Recent time. The heavy minerals in the beaches are zircon, rutile, and ilmenite, which together constitute more than 90 percent of the concentrate (table 22). Monazite, leucoxene, anatase, brookite, garnet, tourmaline, epidote, chlorite, green and brown spinel, chromite, magnetite, sapphire, pyroxenes, hornblende, andalusite, staurolite, columbite (Whitworth, 1931, p. 62–63), gold, platinum metals, and cassiterite make up the rest. The abundance of zircon and rutile is the greatest among beach placers.

The immediate source of the quartz and heavy minerals along the coast near Sydney and north of the Clarence River is soft sandstone of Late Triassic (Whitworth, 1931, p. 73) and Jurassic age. Some of the ilmenite and magnetite, however, and the chromite and platinum, were derived from mafic rocks. The ultimate source of the heavy minerals in the soft sandstone was shown by Gardner (1955, p. 21, 23–24) and Beasley (1950, p. 86, 91) to have been Upper Permian granitic batholiths in eastern Queensland and New South Wales, particularly in the New England area of New South Wales. Silicic phases of the granites and pneumatolytic dikes and veins contain small amounts of monazite and other heavy minerals which resemble in many physical aspects the heavy minerals in the Mesozoic and Recent sediments.

Paleozoic graywacke exposed north of the Clarence River was examined at three localities and did not contain monazite (Beasley, 1950, p. 89–91). The absence of monazite from the three samples is tentatively inferred by Beasley to indicate that the sequence of weakly metamorphosed Paleozoic graywacke, slate, quartzite, and phyllite into which the Permian granites were intruded is devoid of monazite. South of the Clarence River, however, in the drainage basins of the Hastings, Manning, and Hunter Rivers, sand-

TABLE 22.—*Mineralogical composition of concentrates from beach placers, and reserves of monazite, along the South Pacific coast of Queensland and New South Wales, Australia*

[Modified from Gardner (1955, tables 17, 29, 31–33). Symbol used: n.d., no data]

	Composition of concentrate (percent)				Reserves (tons)
	Zircon	Rutile	Ilmenite	Monazite	
Queensland					
Thursday Island near Cape York	4	0.1	95	?	n.d.
Johnstone River 50 miles south of Cairns [1]	1.4	1.8	84	1.2	n.d.
Cannon Vale Beach [2]	Trace	----------	62	?	n.d.
Mackay (Blacks Beach) [3]	9	2	88	.4	n.d.
Facing Island	7	9	80	?	n.d.
Bustard Head	34	4	61	n.d.	n.d.
Burnett Heads	3	2	94	?	n.d.
Frazer Island Beach	25	17	57	.6	500
Inskip Point	n.d.	n.d.	n.d.	n.d.	200
Double Island Point	n.d.	n.d.	n.d.	n.d.	60
Noosa Head	20	17	63	.9	140
Maroochydore	35	16	49	.3	n.d.
Caloundra	21	18	59	2.0	n.d.
Bribie Island	22	18	58	1.1	n.d.
Moreton Island Beach	23	18	58	.9	300
North Stradbroke Island					
Beach	31	37	31	.2	100
Parallel dunes	22	32	46	.4	2,400
Transgressive dunes (low-grade deposits)	28	27	44	.3	18,000
South Stradbroke Island	34	35	30	.5	----------
Beach	n.d.	n.d.	n.d.	n.d.	200
Foredune	n.d.	n.d.	n.d.	n.d.	50
Parallel dunes	n.d.	n.d.	n.d.	n.d.	20
Southport, the Spit	38	37	24	.6	n.d.
Surfers Paradise, Wharf Road, Broadbeach, North Burleigh, North Nobby	38	35	24	.5	1,020
Broadbeach	38	36	25	.5	n.d.
North Burleigh	41	36	23	.7	n.d.
North Nobby to South Nobby	41	33	26	.7	160
Burleigh	47	31	21	1.1	200
Palm Beach	41	36	23	.5	250
Flat Rock Creek (Currumbin)	40	37	23	.5	40
Tugun Beach	42	32	25	.5	110

See footnotes at end of table.

TABLE 22.—*Mineralogical composition of concentrates from beach placers, and reserves of monazite, along the South Pacific coast of Queensland and New South Wales, Australia*—Continued

	Composition of concentrate (percent)				Reserves (tons)
	Zircon	Rutile	Ilmenite	Monazite	
New South Wales					
Tweed Heads to Fingal Point	49	29	22	0. 6	285
Fingal Point to Cudgen Point	46	32	21	. 7	330
Cudgen Point to Norries Head (Cudgen Beach)	51	28	21	. 5	3, 500
Norries Head to Hastings Point	51	29	19	. 8	750
Norries Head to Hastings Point, inland	39	41	19	. 4	180
Hastings Point to Potts Point (Cudgera Beach)	48	32	19	. 7	570
Potts Point to Brunswick Heads	43	36	21	. 6	1, 140
Mooball Beach	41	37	21	. 5	n.d.
Crabbes Creek Beach	39	39	22	. 5	n.d.
New Brighton Beach	47	34	19	. 5	n.d.
Brunswick Heads to Cape Byron (beach)	54	27	18	. 7	900
Cape Byron to Broken Head (Tallow Beach)	53	28	18	. 6	1, 200
Broken Head to Lennox Head (Seven Mile Beach)	53	28	18	. 8	180
Seven Mile Beach 1¼ miles inland	46	36	17	. 8	90
Ballina, beach top just south of the mouth of the Richmond River	55	24	21	. 7	n.d.
North of Evans Head 1–2 miles	44	30	25	1. 0	n.d.
Ballina to Evans Head	n.d.	n.d.	n.d.	n.d.	45
North of Woody Head Beach 2–5 miles	48	31	21	. 8	n.d.
Evans Head to Woody Head Beach	n.d.	n.d.	n.d.	n.d.	210
Macaulays Lead	47	31	21	1. 0	850
Cement Lead and west bank of Jerusalem Creek	46	32	22	. 5	110
Yamba	58	29	13	. 3	n.d.
North of Wooli 8 miles	63	27	10	. 3	n.d.
Woolgoolga	34	41	24	1. 0	n.d.
Laurieton area, south of Grants Head	40	39	20	1. 4	140
Swansea area	n.d.	n.d.	n.d.	n.d.	150
Catherine Hill Bay	50	42	6	1. 0	n.d.
Caves Beach	33	44	22	2. 0	n.d.
Perpendicular Point to Diamond Head	n.d.	n.d.	n.d.	n.d.	80
Terrigal	38	38	21	2. 5	n.d.
Bellambi Beach	38	37	24	. 7	n.d.
Port Kembla [4]	38	29	17	. 2	n.d.
Bulli to Port Kembla	n.d.	n.d.	n.d.	n.d.	35
Shellharbour	35	41	23	. 5	n.d.
North of mouth of Shoalhaven River 1 mile	22	18	59	. 8	n.d.
Narooma	12	7	80	. 16	n.d.
Total					34, 495

[1] Tantalite, 0.9 percent.
[2] Magnetite, 28 percent; hypersthene, 10 percent.
[3] The ilmenite contains a high proportion of magnetite.
[4] Magnetite, 16 percent.

stone of Carboniferous age is the main source for the Recent beach sands and heavy minerals. In their lower beds the Carboniferous sandstones were said by Gardner (1955, p. 22, 30–31) to have received heavy minerals from Devonian granitic rocks and in their upper beds to have received monazite and other heavy minerals from freshly unroofed Carboniferous granites.

Efforts to relate the monazite in the Carboniferous, Mesozoic, and Recent sediments uniquely to stanniferous granitic sources and veins of Devonian, Carboniferous, and Permian age seem to stem from the lack of a study of heavy minerals in the Paleozoic sediments and in the less silicic phases of the granites, and from the many reports that monazite is associated with cassiterite and wolframite in the New England placers of New South Wales. Despite the strong physical resemblance of monazite from the alluvial tin placers to monazite from the beaches, the amount of thorium oxide in the monazite is very different. As is shown below, monazite from the beaches averages 6.6 percent of ThO_2, whereas that from the New England tin and tungsten placers contains about 1 percent of ThO_2. In view of the many analyses showing low-thorium oxide monazite in the New England cassiterite and wolframite placers, the monazite associated there with veins of cassiterite and wolframite must also be low in thorium. Even the silicic granites, over which many tin placers lie and in which tin and tungsten minerals are found, have supplied no thorium-rich monazite to the tin placers. It is evident from analyses that the tin veins and pneumatolytic deposits, certainly, and the silicic granites, possibly, have contributed far less monazite to the present beaches than have other sources. The other sources may include many of the Paleozoic granites other than the silicic and pneumatolytic phases. Possibly some monazite was contributed by Precambrian sources to the Paleozoic sedimentary hosts of the Devonian, Carboniferous, and Permian granites, and ultimately this monazite has been borne to the present beaches. In any event the source of the detrital monazite must contain monazite that has 6–10 times as much thorium as the monazite in the New England tin deposits.

Monazite from Broken Head and Ballina in the Richmond River district, New South Wales, was shown by Mawson and Laby (1904, p. 387) to be radioactive. Monazite-bearing concentrates from beach sand at the mouth of the Johnstone River, Queensland, were reported to contain thorium oxide (Dunstan, B., 1905a, p. 12). Analyses of two placer concentrates, of undescribed mineral composition, from the mouth of the Richmond River near Broken Head showed the following percentages:

[Analyst: Mingaye (1903, p. 222)]

	Percent	
Ce_2O_3	22.42	22.72
La_2O_3, $(Nd,Pr)_2O_3$	22.95	22.78
Y_2O_3	.16	-----
ThO_2	.46	.57
P_2O_5	18.89	18.94
SiO_2	6.68	6.48
Al_2O_3	.14	.19
Fe_2O_3	2.08	1.96
TiO_2	.00	.00
ZrO_2	15.36	15.44
Ta_2O_5	1.10	.86
SnO_2	9.03	9.12
CaO	1.32	1.40
MgO	Trace	Trace
MnO	Trace	Trace
H_2O	.10	.12
Total	100.69	100.58

The amount of thorium oxide in monazite from beach placers between Southport, Queensland, and Byron Bay, New South Wales, was shown by Gardner (1955, p. 49) to be virtually constant at 6.6 ± 0.3 percent. Radiometric comparisons between placer monazite from Byron Bay and monazite from the beaches at North Burleigh in Queensland and Cudgen and Woolgoolga in New South Wales show that the monazite on these three beaches contains 7.3, 7.4, and 6.3 percent of ThO_2 (Gardner, 1955, p. 49). Partial and complete analyses of the rare earths and thorium oxide in placer monazite from the beach at Byron Bay have been made by Murata, Rose, Carron, and Glass (1957, p. 148). The original analysis is published as percentages of the total rare earths plus thorium oxide precipitate equal 100.6 percent. The composition has been recalculated to 68.6 percent of total RE_2O_3 plus ThO_2 in the monazite (H. J. Rose, Jr., written commun., 1958):

[Analysts: *A*, Wylie (1950, p. 165); *B*, Murata and Rose (in Murata and others, 1957 p. 148)]

	Percent	
	A	*B*
Ce_2O_3	27.2	[1] 28.8
La_2O_3	15.5	13.8
Nd_2O_3	11.9	11.6
Pr_2O_3	3.37	[2] 3.1
Sm_2O_3	2.24	1.9
Gd_2O_3	n.d.	1.0
Y_2O_3	n.d.	.9
ThO_2	7.35	7.5

[1] CeO_2.
[2] Pr_6O_{11}.

A chemical analysis of a concentrate containing 98 percent of monazite shows 7.1 percent of ThO_2, equivalent to 7.2 percent of ThO_2 in the pure mineral (Beasley, 1950, p. 80). Monazite of probably the same general composition, but from Tugun Beach about 6 miles south of Burleigh, has a specific gravity of 5.19 (Beasley, 1950, p. 80).

Monazite has been reported from several localities on the Cape York Peninsula, Queensland. It was one of several minerals for which exploration was begun in the vicinity of the Pascoe River in 1956 (Mining Mag., 1956). Monazite makes up 1–9 percent of the heavy minerals in beach sand at the Hey River estuary near Weipa Mission on the Gulf of Carpentaria (Baker and Edwards, 1957a, p. 1). In the southeastern part of the Peninsula inland from Cairns monazite is a common accessory in gold, cassiterite, and wolframite placers. Four analyses of monazite from wolframite deposits near Cairns showed the following average percentage of thorium oxide and a specific gravity of 4.985:

[Analyst: Mingaye in 1907 (1909, p. 282–283)]

	Percent
RE_2O_3	[1] 69.6
ThO_2	[1] 4.1
P_2O_5	25.5
Total	99.2

[1] Average of 4 determinations.

Monazite-rich concentrates from the mouth of the Johnstone River contain 2.6 percent of ThO_2 and 56.1 percent of RE_2O_3 (Dunstan, B., 1913, p. 753). Between the Johnstone River and Cairns at the Astronomer Mine in the Russell River gold field the alluvial concentrates consist chiefly of cassiterite, zircon, and ilmenite, but they also contain a little monazite, rutile, corundum, epidote, and anatase (Baker and Edwards, 1956b). Monazite was found in 1904 by B. Dunstan (1905a, p. 14–15; 1905b, p. 38) in tin and tungsten deposits in the Walsh and Tinaroo mineral fields southwest and west of Cairns. The monazite-bearing placers and the lodes are in granite close to contacts between the granite and slate and granite and quartz porphyry. The monazite contains about 65 percent of RE_2O_3 and has a specific gravity of 5.04 (Dunstan, B., 1905a, p. 15). Various analyses have shown that the monazite from the Walsh and Tinaroo fields contains about 3 percent of ThO_2, and it is said to be too low in thorium oxide and insufficiently abundant to be of economic interest (MacDonald, 1906, p. 15; New Zealand Mines Rec., 1906, p. 402). Around 1905 a few tons of monazite had been saved as a byproduct at the wolframite mines, but none was sold (Dunstan, B., 1906, p. 157). Localities known to contain some monazite include Fingertown, California Creek, Emu Creek, several places on Nettle Creek, Bamford, Ord, and near Coolgara (MacDonald, 1912, p. 15; Dunstan, B., 1913, p. 753; Ball, 1915, p. 7). At Fingertown the monazite is associated with wolframite, biotite, and topaz in a quartz lode, and at California Creek it occurs with wolframite, molybdenite, cassiterite, arsenopyrite, pyrite, mica, and quartz in greisen. Wolframite and cassiterite placers at California Creek contain monazite. On Emu Creek monazite occurs with cassiterite in placers 3 miles north of Fossilbrook, and with cassiterite, mica, chlorite, clay, and quartz at Emuford. The Nettle Creek occurrences, 10–14 miles north of Mount Garnet, are placers and an association of monazite with wolframite, cassiterite, tourmaline, and arsenopyrite in irregular masses of quartz in greisen. At Bamford the monazite apparently comes from wolframite placers in an area along the contact of biotite granite intrusive into porphyry (Ball, 1915, p. 59–64).

Very small amounts of monazite are associated with cassiterite in placers in the Annan River tin field, Cooktown district, Queensland (Saint-Smith, 1915, p. 556–557; 1916, p. 165). Sparse grains of kyanite occur in the placers along Wallaby Creek in the Annan River tin field.

A group of monazite-bearing pegmatite dikes are exposed in gneissic granite and micaceous hornblende schists about 5 miles southwest of Mount Isa in western Queensland. From that point they extend at least 12 miles southward in a belt only about a mile wide. The dikes contain beryl, monazite, cassiterite, muscovite, tantalite, fluorite, and tourmaline (Blanchard and Hall, 1942, p. 35–37; David and Browne, 1950, p. 316; Shepherd, 1938, p. 95). Specimens of monazite from the Mica Creek pegmatites attain a maximum length of 4 inches (Connah, 1938). Four analyses show that the monazite contains from 5.73 to 6.22 percent of ThO_2 (Blanchard and Hall, 1942, p. 59).

A sample of placer sand from Queensland, location and mode of occurrence unknown, was examined by the Imperial Institute [London] and was reported (Imp. Inst. [London], 1905, p. 233) to contain 1.2 percent of monazite.

The Stanthorpe mineral field southwest of Brisbane and near the border of New South Wales has monazite-bearing cassiterite placers at Broadwater Creek in the Darling Downs (Dunstan, B., 1913, p. 753).

The monazite first analyzed in New South Wales had a specific gravity of 5.001 and the following percentage of thorium oxide in small crystal fragments of detrital monazite from the Vegetable Creek tin fields:

[Analyst: W. A. Dixon (in Wood, 1882, p. 26)]

	Percent
Ce_2O_3	36. 64
$(La, Nd, Pr)_2O_3$	30. 21
ThO_2	1. 23
P_2O_5	25. 09
SiO_2	3. 21
Al_2O_3	3. 11
MgO	Trace
MnO	Trace
Total	99. 49

This locality is about 25 miles north-northeast of Emmaville in the New England granitic area of northeastern New South Wales.

Monazite is a common but not abundant accessory in the cassiterite and wolframite deposits in the New England region (Carne, 1912, p. 91; Raggatt, 1925, p. 16; David and Browne, 1950, p. 316). During the late 1800's and early 1900's, many samples of monazite from widely separated tin and tungsten placers in the region were analyzed in a search for commercially acceptable thorium ore, but only in rare samples did the monazite contain more than 2 percent of ThO_2 (Carne, 1912, p. 91). One sample of monazite from Torrington and two samples from a point 20 miles west of Torrington were shown by Mawson and Laby (1904, p. 387) to contain 0.39, 1.5, and 1.8 percent of ThO_2. Monazite associated with wolframite in the vicinity of Torrington was said to have only a trifling content of thorium oxide (Hintze, 1922, p. 344). Two samples of monazite-bearing alluvial sand from Torrington (Carne, 1912, p. 92) contained 72.30 and 67.12 percent of RE_2O_3 and 0.38 and 0.71 percent of ThO_2. The first sample analyzed seems to have been virtually pure monazite, but the second is a concentrate shown to have 4.98 percent of metallic bismuth. The monazite in this concentrate probably had 0.75 or 0.80 percent of ThO_2. A sample of monazite from the vicinity of Battery Mountain between Torrington and Deepwater contained 70.71 percent of RE_2O_3 and 0.77 percent of ThO_2 (Carne, 1912, p. 91). Three analyses of monazite-bearing concentrates from The Gulf, northwest of Emmaville, showed from 0.31 to 0.65 percent of ThO_2

(Carne, 1912, p. 92) in material having possibly 40–100 percent of monazite. Estimates indicate that probably the amount of thorium oxide in the monazite in these was 0.35–1.6 percent. Five samples of monazite from The Gulf were reported by Mawson and Laby (1904, p. 387) to contain an average of 0.6 percent of ThO_2. Monazite that occurs as inclusions in feldspar and quartz in a wolframite-bearing pegmatitic vein at Blatherarm Creek in the Vegetable Creek tin field contained the following percentage of thorium oxide and had a specific gravity of 5.119:

[Analyst: Anderson (1904, p. 258–259)]

	Percent
Ce_2O_3	35.70
(La, Nd, Pr)$_2O_3$	30.73
Y_2O_3	Trace
ThO_2	1.63
P_2O_5	28.20
SiO_2	.49
Al_2O_3, Fe_2O_3	2.23
H_2O	.34
Total	99.32

The vein is 8 inches wide, consists of orthoclase, quartz, biotite, wolframite, and monazite and fills a fracture in coarse biotite granite. Two monazite-bearing concentrates from a stream 20 miles west of Torrington were shown by Carne (1912, p. 92) to contain 1.56 and 1.81 percent of ThO_2. Possibly these are the same samples reported as monazite by Mawson and Laby (1904, p. 387). Although neither concentrate seems to have consisted entirely of monazite, the content was perhaps 95 and 80 percent of monazite, and possibly the content of the monazite was about 1.6 and 2.2 percent of ThO_2, respectively.

Monazite that had the following percentage of thorium oxide was found at Black Swamp, about 5 miles northwest of Torrington; it occurs with cassiterite and wolframite:

Analyst: Mingaye in 1907 (1909, p. 283)]

	Percent
RE_2O_3	[1] 65.23
ThO_2	[1] 4.11
P_2O_5	25.75
Total	95.09

[1] Average of two determinations.

Monazite separated from an alluvial concentrate from Stannum contained the following percentage of thorium oxide:

[Analyst: Wylie (1950, p. 165)]

	Percent
Ce_2O_3	25.6
La_2O_3	12.6
Nd_2O_3	9.90
Pr_2O_3	2.89
Sm_2O_3	1.99
ThO_2	6.18

At Warialda, New South Wales, monazite occurs in a vein of bismuth carbonate (Mawson and Laby, 1904, p. 387). Zircon sand 18 miles northeast of Dubbo, and gem placers 15 miles south of Oberon, near Mount Werong, contain monazite (Mingaye, 1909, p. 283).

Monazite, thorite, and davidite occur as scattered disseminations and small veins in shear zones in metasedimentary gneiss and schist of early Precambrian age in the Thackaringa area of the Broken Hill district, New South Wales (Rayner, 1955, p. 62–69). In several places, granitic gneiss, amphibolite, and metamorphosed limestone are present. The metamorphic rocks are of upper amphibolite grade and locally include sillimanite gneiss. The metasedimentary rocks are migmatized, pegmatized, and widely intruded by aplite related to several ages of intrusion and replacement. About 95 percent of the area is covered with detrital sand, soil, rock fragments, and windblown sand. Thin layers of detrital heavy minerals, chiefly garnet, magnetite, ilmenite, and monazite, have been deposited along small watercourses in the western part of the district, but concentrations of monazite and other heavy minerals in the soil mantle have not been reported. No evidence is given for exploitable deposits of monazite in the area, but the assemblage of high-grade gneisses is here interpreted to suggest a possible wider presence of monazite in this district than has been reported.

Monazite is a minor accessory detrital mineral in sedimentary rocks of the Lower Triassic Narrabeen Series which crops out along the coast of New South Wales between Stanwell Park and Tuggerah Lake (Culey, 1933, p. 344–359). Monazite was observed in 6 of 19 samples. It was found only in sandstone and only in the vicinity of Terrigal and Pelican Point. Samples of tuff and shale from the same area did not contain monazite. The mineralogical composition of the monazite-bearing concentrates is given in table 23.

Small amounts of detrital monazite from three sedimentary rocks of Permian age were reported by Carroll (1940, p. 636–640) to have been found in outcrops west of Newcastle, New South Wales, and from depths of 6,265 to 6,291 feet in a test well at Kulnura about 37 miles southwest of Newcastle. The monazite occurs as sparse, well-rounded grains among the heavy minerals separated from hard gray compact calcareous Kulnura grit, hard gritty calcareous Muree tillite, and fine- to coarse-grained greenish slightly calcareous Ravensfield sandstone. The absolute amount of monazite in these rocks is very small. Table 24 shows the abundance of monazite and the associated heavy min-

TABLE 23.—*Mineralogical composition of monazite-bearing concentrates from sandstones in the Narrabeen Series of Triassic age in New South Wales, Australia*

Analyst: Culey (1933, p. 361). Symbols used: A, abundant (46–75 percent); VC very common (26–45 percent); C, common (6–25 percent); R, rare (1–5 percent); S, scarce (>1 percent); P, present; -- not determined; Ab, absent]

	1	2	3	4	5	6
Heavy minerals in the sandstone percent	0.05	0.07	0.03	0.03	0.1	0.01
Chalcopyrite	Ab	Ab	Ab	Ab	S	Ab
Garnet	R	S	Ab	R	R	R
Magnetite	R	Ab	Ab	Ab	Ab	Ab
Picotite	R	C	C	C	R	R
Spinel	Ab	Ab	Ab	Ab	Ab	S
Anatase	C	C	C	C	R	C
Rutile	R	R	R	R	R	R
Zircon	A	A	VC	A	A	A
Apatite	Ab	Ab	Ab	R	Ab	Ab
Ilmenite	R	Ab	R	Ab	C	R
Tourmaline	C	C	C	C	R	C
Barite	Ab	C	C	Ab	Ab	Ab
Brookite	Ab	S	Ab	Ab	S	Ab
Hypersthene	Ab	Ab	Ab	Ab	Ab	S
Biotite	------	------	Ab	P	Ab	Ab
Monazite	S	S	S	R	R	S
Muscovite	------	------	P	P	Ab	Ab

1. Tudibaring (sandstone).
2. Avoca (sandstone).
3. Avoca (fine-grained sandstone).
4. Terrigal (sandstone).
5. Terrigal (green sandstone).
6. The Entrance (white sandstone).

TABLE 24.—*Mineralogical composition, in percent, of monazite-bearing concentrates from sedimentary rocks of Permian age in New South Wales, Australia*

[Analyst: Carroll (1940, p. 640). Symbols used: Ab, absent; L, large; M, medium; S, small; P, present]

	1	2	3	4	5	6	7	8
Size of concentrate	M	S	S	S	L	L	L	S
Magnetite	Ab	P	Ab	P	Ab	Ab	Ab	Ab
Ilmenite	13	33	17	11	35	3	6.5	6.7
Leucoxene	22	23	31	32	25	32	31	32
Pyrite	P	Ab	P	P	Ab	Ab	P	Ab
Zircon	26	15	35	24	20	45	33	46
Tourmaline	30	24	14	28	10	7	6.5	5
Rutile	.5	Ab	2	1	2.7	6	2	5
Anatase	1	2	.1	Ab	.2	2	3	2
Sphene	5	.5	.5	2	1	7	7	4
Garnet	Ab	Ab	Ab	Ab	3.5	.5	10	.3
Monazite	1.5	.5	.1	.2	.2	1	.7	.7
Epidote	.5	.5	.1	Ab	Ab	Ab	Ab	Ab
Chlorite	P	Ab	Ab	Ab	.5	Ab	Ab	Ab
Picotite	Ab	Ab	Ab	P	.4	.3	.4	Ab
Barite	P	P	Ab	Ab	Ab	Ab	Ab	Ab
Brookite	Ab	Ab	Ab	P	Ab	Ab	Ab	Ab
Carbonate	P	P	P	P	P	Ab	P	Ab
Mica	Ab	Ab	Ab	Ab	Ab	P	P	P

1–4. Kulnura grit at depths of 6,265, 6,276, 6,290, 6,291 ft in a test well at Kulnura, about 37 miles southwest of Newcastle.
5. Muree tillite at Campbell's Hill, West Maitland.
6–7. Ravensfield sandstone at Ravensfield quarry, 3 miles due west of West Maitland.
8. Ravensfield sandstone at Rutherford.

erals in the 8 out of 13 samples that were monazite bearing.

Virtually the same suites of heavy minerals was reported by Culey (1933, p. 361) from sandstone of Triassic age in the same area. Similarity in the suites of heavy minerals from sedimentary rocks of Permian and Triassic age in the same region was interpreted by Carroll (1940, p. 645–646) as showing that the sediments were derived from the same distributive province, which is thought to be an area underlain by an old sedimentary series and granite. This ancestral distributive province may have been the source of monazite along the present coast.

Repeated efforts to find commercially acceptable monazite in stream placers in Queensland and New South Wales have been unsuccessful (Raggatt, 1925, p. 16). Beach placers in both states, however, have yielded acceptable monazite since 1947. The amount of monazite recovered at the beaches between 1947 and 1952 is here estimated from Gardner's account (1955, p. 68–102) to have been about 660 tons in 8,450 tons of concentrate.

Washings made after storms and taken from the beach at the Spit between South Stradbroke Island and Southport, southern Queensland, have been the source of about 1,000 tons of concentrate per year since 1947. The concentrates contained perhaps 0.5 percent of monazite. Between Southport and Coolangatta, Queensland, 40 tons of monazite in high-grade concentrates and 371 tons of monazite in low-grade concentrates were produced between 1947 and 1952. Most of this output came from Broadbeach and North Burleigh, but some monazite was mined at Tugun, Burleigh, Palm Beach, Flat Rock Creek, and Main Beach. In northern New South Wales at Tallow Beach and Seven Mile Beach, 145 short tons of concentrates averaging more than 90 percent of monazite was produced between 1949 and the end of 1952. Prior to 1949 several hundred tons of concentrate containing 20 percent of monazite was stockpiled at Seven Mile Beach. The region between Evans Head and Woody Head in northern New South Wales, particularly around Macaulays Lead, was worked between 1890 and 1900 for gold, the platinum metals, and cassiterite. Again between 1905 and 1910 the area was mined for these metals and monazite. No record of the early output of monazite was preserved. In 1950 about 200 tons of table concentrate having some monazite was stockpiled. About 102 tons of high-grade monazite concentrate was produced from the coastal deposits of Queensland and New South Wales in 1956 (Hudson and Blaskett, 1958, p. 161).

Australian output of monazite between 1950 and 1954, mined entirely from the beaches of Queensland and New South Wales, is given in table 25. The production figures are very different from those supplied the writer by John G. Parker of the U.S. Bureau of Mines (table 26).

The resources in monazite along the coast of Queensland and New South Wales must considerably exceed the 34,495 tons given in table 22 as the reserves of these beaches.

TABLE 25.—*Monazite, in short tons, produced in New South Wales and Queensland, 1950–54*

Compiled from Australia Bur. Mineral Resources, Geology and Geophysics, 1951; p. 15, 109; 1953, p. 98; 1954, p. 118 and from Carver, 1954, p. 8; 1955, p. 8]

	Concentrate produced			Monazite produced		
	New South Wales	Queensland	Total	New South Wales	Queensland	Total
1950	33.6	5.6	39.2	31.4	4.4	35.8
1951 [1]	35.8	2.3	38.1	33.6	2	35.6
1952			128.8			118.7
1953			220.6			202.8
1954 [2]			88.5			78.4

[1] Monazite sales were 49.3 short tons in 1951 and 128.8 short tons in 1952.
[2] Estimate.

TABLE 26.—*Monazite, in short tons, produced in Australia, 1948–61*

[J. G. Parker, U.S. Bureau of Mines (written commun., 1962)]

	High-grade concentrate	Concentrate	Low-grade concentrate	Total
1948		941.9		941.9
1949	208.3			208.3
1950	174.7			174.7
1951	328.2		45.9	374.1
1952		128.8		128.8
1953	77.3		206.1	283.4
1954	79.5		118.7	198.2
1955	166.9		49.3	216.2
1956	104.2		163.5	267.7
1957	147.8			147.8
1958	473.8			473.8
1959	370.7			370.7
1960	386.0			386.0
1961		1,739.0		1,739.0
Total				5,910.6

SOUTH AUSTRALIA

Low-thorium oxide monazite has been found in veins, disseminated deposits, and placers in South Australia. Most of the deposits are in Precambrian and Cambrian metasedimentary rocks in the Flinders-Mount Lofty Ranges which lead northward from Adelaide. None of the occurrences is a source for thorium.

Small crystals of monazite from auriferous quartz at the Kings Bluff gold mine near Olary (Mawson, 1906, p. 192; Mining Jour., 1909) were shown to contain the following percentage of thorium oxide:

[Analyst: Wylie (1950, p. 165)]

	Percent
Ce_2O_3	28.4
La_2O_3	19.5
Nd_2O_3	12.2
Pr_2O_3	3.46
Sm_2O_3	2.43
ThO_2	.18

Pneumatolytic disseminations of monazite, tourmaline, and apatite in corundum-mica schist were described by Mawson (1916, p. 263–264; Keystone, 1911) from an area of variously crushed and mylonitized orthogneiss, sillimanite schist, and cordierite-mica schist between Mount Pitts and Mount Painter (Mawson, 1923, p. 376–379) in the Flinders Range. The monazite is ordinarily embedded in or surrounded by the mica, but where black tourmaline is abundant, the monazite is included in the tourmaline. Much of the monazite is euhedral. A clean concentrate of the monazite was analyzed by J. C. H. Mingaye (Mawson, 1916, p. 264) and was found to contain 0.16 percent of ThO_2 and 66.48 percent of RE_2O_3. About 4 miles southwest of Mount Painter, a crushed quartz-feldspar porphyry consisting of strained quartz and crushed orthoclase in a groundmass of fine-grained felsic granules contains common accessory magnetite and sphene and scarce small grains of honey-yellow to bottle-green monazite (Mawson, 1923, p. 379). Low-thorium oxide monazite also occurs in the Mount Painter area in some of the pegmatite dikes that contain radioactive minerals and in some of the schists invaded by the pegmatites (David and Browne, 1950, p. 317).

Thorium-poor monazite has been discovered in auriferous gravel at several places in the Mount Lofty Ranges and in cassiterite-bearing quartz from Glenforth southeast of Tarcoola in the south-central part of South Australia (David and Browne, 1950, p. 317).

Thorium-rich monazite of no economic importance occurs in Precambrian dikes of rutile-bearing albite pegmatite in slightly metamorphosed quartzose schists in the Normanville district of the Flinders Range about 40 miles south of Adelaide. At the Yankalilla gorge 4.5 miles southwest of Normanville, the monazite is most abundant in thick envelopes of biotite that enclose the pegmatites (Thomas, 1924, p. 259–263). The monazite is typically formed as augen which reach a maximum size of 6 by 4 by 3 inches and are elongated parallel to the strike of the schists. Euhedral crystals are scarce. Autoradiographs of large polished pieces of monazite clearly outline areas of different intensity of radioactivity. The most radioactive areas correspond to darker colored parts of the specimen. In one sample the more radioactive parts were enclosed by well-defined boundaries that may have been crystal faces, but in most pieces of monazite the zones of greatest radioactivity are irregularly distributed. Analysis of this monazite, specific gravity of 4.95, disclosed the following percentage of thorium oxide:

[Analyst: Thomas (1924, p. 262; see also Holmes, Arthur, 1931, p. 387)]

	Percent		Percent
Ce_2O_3	25.09	TiO_2	1.70
La_2O_3 (group)	24.32	Ta_2O_5	.00
Y_2O_3 (group)	4.00	CaO	2.60
ThO_2	10.7	PbO	.55
U_3O_8	.00	H_2O-	[1] .40
P_2O_5	26.88	H_2O+	[1] 1.52
SiO_2	1.65		
Al_2O_3	.00	Total	100.26
Fe_2O_3	.85		

[1] Relatively high percentage of combined water is regarded by Thomas as confirming microscopic evidence that the monazite is altered. Combined water is interpreted as partial hydration of the rare-earth bases and simultaneous leaching of phosphoric acid.

Another analysis of monazite from a rutile-bearing pegmatite in the Normanville district showed the following percentage of thorium oxide:

[Analyst: Wylie (1950, p. 165)]

	Percent
Ce_2O_3	21.9
La_2O_3	10.5
Nd_2O_3	11.7
Pr_2O_3	3.03
Sm_2O_3	2.23
ThO_2	19.4

At Myponga Hill along the road between Yankalilla and Adelaide, isolated elongate masses of monazite as much as 2 inches long occur in what was described as a shear zone in metasedimentary rocks of Precambrian age (Rowley, 1956, p. 63). The possible sheared zone is between two veins composed of ilmenite and hematite. It is about 3 feet wide and consists of a soft mixture of talc, mica, and tremolite asbestos containing the elongate pieces of monazite. Although the talcose mixture extends beyond the ilmenite-hematite veins, the monazite is restricted to the material between the veins. Radiometric analysis of selected pieces of the monazite indicated that the monazite contains about 8 percent of ThO_2.

Placer monazite with more than 8.0 percent of ThO_2 was found at Daws Diggings on Kangaroo Island southwest of Adelaide (David and Browne, 1950, p. 317). The monazite is associated with rutile, zircon, corundum, kyanite, tourmaline, and gold. The abundance of thorium oxide and the associated minerals and the geographic proximity to the Normanville deposits suggest that the monazite on Kangaroo Island may have been derived from terrain similar to that at Normanville.

Rutile-bearing pegmatite dikes in hornfels and schists at Strathalbyn, South Australia, contain small crystals of monazite (Wilson, A. F., 1943) which commonly occur at the contact between the dikes and wallrocks, especially where black tourmaline is an accessory in the dike. No analysis is given.

Monazite has not been mined in South Australia.

TASMANIA

Monazite seemingly was first noticed in Tasmania between 1893 and 1896; it was not mentioned by Petterd (1894) in 1893 when he listed the minerals known to occur in Tasmania but was mentioned in a paper read in 1896 (Petterd, 1897, p. 27). Its discovery was attributed by Petterd (1910, p. 121) to Prof. Stelzner of the Mining School at Freiberg, Saxony, who observed monazite in ore from the Mount Bischoff district. By 1902 Petterd (1902, p. 82) wrote that monazite had been found in most of the streams draining granite in Tasmania. Most Tasmanian fluvial tin placers contain monazite. Monazite has been found on the beaches, and it occurs in placers on King Island between Victoria and Tasmania.

Monazite-bearing cassiterite placers in northeastern Tasmania are associated with outcrops of Devonian porphyritic biotite granodiorite and muscovite-biotite granite intrusive into Silurian and older slates and quartzites (David and Browne, 1950, p. 292). Along the Ringarooma River (Nye, P. B., 1925, p. 28) and in the Scottsdale district (Petterd, 1910, p. 121), the monazite and cassiterite are accompanied by tourmaline topaz, corundum, and zircon, all apparently derived from the granodiorite and granite. Monazite from a placer in the Scottsdale district was shown to contain the following percentage of thorium oxide:

[Analyst: Wylie (1950, p. 165)]

	Percent
Ce_2O_3	26.7
La_2O_3	14.4
Nd_2O_3	11.0
Pr_2O_3	3.23
Sm_2O_3	2.22
ThO_2	7.29

According to Petterd (1910, p. 121), attempted mining of the placer monazite in the Scottsdale area failed in the early 1900's because the monazite contained only 2 percent of ThO_2.

Some of the lode mines in the Moina, Mount Claude, and Lorinna areas around the Forth River in the north-central part of Tasmania were reported (Reid, A. M., 1919, p. 47–48) to have monazite. The mineral occurs in quartz veins with cassiterite, wolframite, bismuthinite, fluorite, topaz, and beryl. Reid stated that no analyses of this monazite were made because other Tasmanian monazites analyzed prior to this study had less than 3 percent of ThO_2 and were unacceptable in commerce.

Black sand, reported to contain titaniferous minerals, zircon, monazite, cassiterite and gold, the last two minerals in commercial abundance, was being mined near Low Head on the north coast of Tasmania in 1941 (Mining Jour., 1941a). A concentrate was prepared at the beach using Wilfley tables and sea water for the processing, and the concentrate was shipped to Melbourne for further treatment. Output of monazite, if any, is not known.

The Stanley River tin field north of Zeehan in western Tasmania contains detrital monazite, but monazite has not been observed in the cassiterite veins (Waterhouse, 1914, p. 113–114; Petterd, 1903, p. 28; Imp. Inst. [London], 1925; Engineer, 1925). The detrital monazite is thought to originate as disseminated grains in the local granite, for it was discovered in many short creeks heading in and flowing across granite. No analyses are given for the monazite; Waterhouse inferred it to have but little thorium oxide. Monazite is rather abundant at the North Heemskirk tin field (David and Browne, 1950, p. 316), but in the South Heemskirk placers it is an uncommon accessory (Waterhouse, 1916, p. 212). In the Mount Bischoff tin field, monazite derived from granite intrusive into slates (Twelvetrees and Petterd, 1898, p. 120) is widely distributed in the placers of the South Bischoff area. It contains from 2.5 to 3.0 percent of ThO_2 (Reid, A. M., 1923, p. 53). Ocher-yellow crystals of monazite encrusting wolframite have been found in quartz ore from Mount Bischoff (Hintze, 1922, p. 344). Monazite was reported to occur at Mount Stormont (Mining Jour., 1941b), but details are lacking. It is also found in the Yellow Band Plains (Nye and Blake, 1938, p. 96) and in the Khaki Mine at the foot of the Meredith Range (Petterd, 1910, p. 121).

The beach sands of King Island in Bass Strait between Victoria and Tasmania were the source of monazite found to contain the following percentage of thorium oxide:

[Analyst: Wylie (1950, p. 165)]

	Percent
Ce_2O_3	28.3
La_2O_3	16.8
Nd_2O_3	11.0
Pr_2O_3	3.12
Sm_2O_3	2.72
ThO_2	6.09

In the early 1900's, black sand at the mouth of the Frazer River was treated for monazite and cassiterite. According to Debenham (1910, p. 574), "the monazite was separated without great difficulty, but its low percentage of thorium forbade its ready sale, and the tin concentrates did not pay for the cost of working." The Frazer River drains a broad area of alluvium covering slates and schists (Debenham, 1910, p. 572); thus, the ultimate source of the monazite is not known. No record of the production of monazite at the Frazer River is given.

In the eastern part of Tasmania, monazite occurs on the south side of Mount Stronach in the Pioneer tin mine (Petterd, 1903, p. 28; 1910, p. 121) and on the east coast (Nye and Blake, 1938, p. 96).

VICTORIA

Placer monazite has been found on the beaches of eastern and southern Victoria and in streams in the northern, eastern, and western parts of the State.

Layers of black sand along the beach 3 miles southwest of Mallacoota Inlet, East Gippsland, Victoria, contain 15–70 percent of heavy minerals (Baker and Edwards, 1956c; 1957b, p. 1). In five samples, monazite made up 0.2–1.0 percent and averaged 0.4 percent of the black sand. Monazite, separated from the zircon and rutile with which it occurs on the beach at Cape Everard southwest of Mallacoota Inlet, was shown to contain the following percentage of thorium oxide:

[Analyst: Wylie (1950, p. 165)]

	Percent
Ce_2O_3	26.6
La_2O_3	15.7
Nd_2O_3	10.6
Pr_2O_3	2.76
Sm_2O_3	2.36
ThO_2	5.20

The source may be granitic rocks and invaded Paleozoic sedimentary rocks at and north of the Cape.

Orange-yellow alluvial monazite occurs with green epidote and small amounts of ilmenite, magnetite, and scarce sapphires in the upper valley of Pinch Swamp Creek in the Bonang district of East Gippsland (Copland, 1905, p. 3–6). The monazite-bearing alluvium is a coarse gravel of quartz and greenstone bound by blue clay. Throughout the valley where monazite is found the gravel rests on decomposed diorite. Monazite is disseminated through the diorite and occurs in the contact-metamorphosed Ordovician slate into which the diorite is intruded. The monazite contains 6.6 percent of ThO_2, 29.0 percent of Ce_2O_3, and 27.4 percent of other rare earths.

Elsewhere in eastern Victoria, monazite has been found in gravel in the Koetong area of East Gippsland, in the Mitta Mitta River southeast of Albury, at Bethanga, and in South Gippsland (David and Browne, 1950, p. 316).

Along the south coast of Victoria, small amounts of monazite have been reported from Point Addis, Phillip Island, and the Mornington Peninsula. At Point Addis, black beach sand was described (Baker and Edwards, 1956d, p. 1) as consisting dominantly of hematite, maghemite, and limonite mixed with some ilmenite, rutile, and pyrite and about 1 percent of minor accessories which are principally zircon, kyanite, tourmaline, and monazite. Black sand of little economic value is found along the beaches of Phillip Island (Beasley, 1957). Six concentrates from the deposits contain 67 percent or more of limonite, magnetite, and ilmenite. Olivine makes up 3.2–10.4 percent of the concentrate in each of the six samples. Zircon, augite, rutile, leucoxene, tourmaline, epidote, topaz, spinel, sphene, and garnet are present. A trace of monazite was seen in three of the six concentrates. Most of the heavy minerals come from Tertiary volcanic rocks that crop out near the beaches, but the immediate source of the monazite, zircon, rutile, tourmaline, topaz, epidote, garnet, spinel, and sphene are Jurassic and Tertiary sedimentary rocks on the island and the adjacent mainland. Beach sands from the Mornington Peninsula contain 3.7 percent of heavy minerals, but monazite is scarce (Baker and Edwards, 1956e, p. 1). Concentrates consist chiefly of ilmenite, with some magnetite and hematite, a little zircon, tourmaline, rutile, and leucoxene, and a trace of monazite.

Heavy-mineral sands are not naturally concentrated in sufficient quantity on these southern beaches to be economically recoverable, nevertheless monazite-bearing sands are present on bay and ocean beaches. Monazite was found in 7 out of 11 samples of heavy-mineral beach sand collected by Baker (1945, p. 11–16) from about Kilcunda. The composition of these monazite-bearing concentrates is shown in table 27. Magnetite and ilmenite are generally the chief components, but at Ricketts Point the concentrates consist mainly of ilmenite and zircon, and at Torquay mainly of magnetite and zircon. At Balnarring, Point Hayley, and Kilcunda the natural concentrates contain a great assortment of heavy minerals, but except for magnetite, ilmenite, and zircon, the other minerals, including monazite, are represented by only a few grains each. The order of abundance is magnetite, ilmenite, zircon, rutile, garnet, and tourmaline. Monazite occurs as pale-lemon-yellow oval grains and is uncommon in all samples.

TABLE 27.—*Mineralogical composition of monazite-bearing concentrates from bay and ocean beaches of Victoria, Australia*

[Analyst: Baker (1945, table 2, p. 16). Symbols used: P, present; Ab, absent]

	Bay beaches				Ocean beaches		
	Saint Kilda	Ricketts Point	Davey's Bay	Balnarring	Torquay	Point Hayley	Kilcunda
Anatase	P	Ab	P	Ab	Ab	Ab	Ab
Augite	P	Ab	Ab	P	Ab	P	P
Brookite	Ab	Ab	Ab	Ab	Ab	Ab	P
Cassiterite	P	Ab	Ab	P	P	Ab	Ab
Clinozoisite	P	Ab	P	Ab	Ab	Ab	Ab
Epidote	Ab	Ab	Ab	P	Ab	P	P
Garnet	Ab	P	P	P	Ab	P	P
Hypersthene	P	Ab	Ab	P	Ab	P	P
Ilmenite	P	P	P	P	Ab	P	P
Kyanite	Ab	Ab	Ab	P	Ab	Ab	Ab
Leucoxene	P	P	Ab	P	P	P	P
Limonite	Ab	P	P	Ab	Ab	P	P
Magnetite	P	Ab	P	Ab	P	P	P
Monazite	P	P	P	P	P	P	P
Olivine	P	Ab	Ab	Ab	Ab	Ab	P
Rutile	Ab	P	P	P	P	P	P
Sphene	Ab	Ab	Ab	Ab	Ab	P	Ab
Spinel	Ab	Ab	Ab	Ab	Ab	P	P
Staurolite	Ab	P	Ab	P	Ab	P	Ab
Topaz	Ab	Ab	Ab	P	Ab	P	P
Tourmaline	P	P	Ab	Ab	P	P	P
Zircon	P	P	P	P	P	P	P

The number of cycles of erosion and transportation of the heavy minerals at each beach was not determined by Baker (1945, p. 16), but he inferred that some species may have participated in five or more cycles. The heavy minerals at Saint Kilda are thought to come partly from the drainage basin of the Yarra River. At Ricketts Point they are derived from Red Beds of Tertiary age, and at Davey's Bay from ferruginous sedimentary rocks of Tertiary age and from granodiorite. Sources for the heavy minerals at Balnarring include Tertiary basalt, Devonian granitic rocks, and metasedimentary rocks. Around Torquay the main sources were sedimentary rocks of Tertiary age. At Point Hayley and Kilcunda the source is arkose of Jurassic age, but at Kilcunda some magnetite and ilmenite may come from dikes of olivine basalt that cut the Jurassic sedimentary rocks (Baker, 1945, p. 17–18).

Monazite is present in variable quantities in cassiterite-bearing concentrates from stream sand and residual soil from granite in the upper part of the drainage basin of the La Trobe River (Baker, 1959).

A monazite-bearing volcanic ash bed of probable Pleistocene age is associated with limestone in small lake deposits exposed in three quarries 1–2 miles east of Coimadai about 35 miles northwest of Melbourne (Coulson, 1924, p. 169–174). The volcanic ash contains many fragments of slate, shale, and sandstone. The ash was inferred by Coulson to have been deposited simultaneously with stream-transported debris in the lake basins. Quartz is the most abundant mineral in the ash; biotite and feldspar are present, and picotite, monazite, and pyrite are sparsely present. This is the only volcanic ash, exclusive of carbonatite complexes, in which monazite has been observed. No evidence is presented to show whether the monazite is of pyroclastic origin or was derived from land waste and brought into the lake deposits by the streams.

Monazite was reported from Stawell and Nhill in the southern Mallee country of western Victoria (David and Browne, 1950, p. 316).

No commercial production of monazite was recorded for Victoria.

WESTERN AUSTRALIA

The occurrences of monazite in Western Australia have been summarized by Simpson (1952, p. 248–252) in his text on the mineralogy of the State from discussions previously published (Simpson, 1912a; 1912b, p. 94; 1914, p. 43; and 1919, p. 5). The following material, unless otherwise noted, is taken from Simpson's summary descriptions.

Monazite occurs as an accessory mineral in plutonic silicic igneous and metamorphic rocks, in consolidated and unconsolidated sediments, and in soils of Western Australia. It has been found in lake sediments, in the beds of streams, and along the oceanic beaches, but none of these occurrences has been shown to be an industrial source for monazite.

Precambrian gneiss in the Yilgarn gold field in the southern part of the State, particularly gneiss exposed around Southern Cross, contains monazite. Heavy residues from the overlying soil are commonly monazite bearing. In the Pilbara gold field (Mawson and Laby, 1904, p. 387) in the northern part of the State, concentrates from the upper Precambrian fluvioglacial Nullagine conglomerate at Nullagine contain monazite, barite, zircon, xenotime, rutile, cassiterite, magnetite, ilmenite, chromite, tantalite, pyrite, and gold.

Permian sedimentary rocks at Wandagee (Wandagee Station) in the northwestern part of the State locally contain detrital grains of monazite (Higgins and Carroll, 1940, p. 145–156). Sixteen out of twenty-three samples of fine-grained argillaceous and micaceous sandstone, sandy shale, and coarse-grained sandstone contained monazite (table 28). In most of the rocks the concentrate makes up less than 1 percent of the total weight, and monazite is less than 1 percent of the concentrate. At Wandagee Hill, coarse-grained sandstone contains as much as 2 percent of heavy minerals, and monazite constitutes 3 percent of the concentrate. In each of the samples the monazite forms round yellowish-green grains. Metamorphic and igneous rocks of Precambrian age are thought to be the source of the detrital monazite in these sandstones.

Sedimentary rocks of Permian age at the Irwin River in the southwestern part of the State contain small amounts of detrital monazite. The monazite is most abundant in sediments adjacent to seams of coal.

The Donnybrook sandstone of Triassic age and derived soils in the southwestern part of Western Australia are monazite bearing.

Examination of the heavy residues from six samples of greensand and chalk of Cretaceous age exposed around Gingin in the southwestern part of the State disclosed a small amount of detrital monazite in one specimen of greensand from Poison Hill, 3.7 miles north-northwest of Gingin (Carroll, 1941, p. 87–90). Abundant ilmenite and magnetite make up most of the heavy minerals in the monazite-bearing sample. Zircon, tourmaline, rutile, kyanite, sillimanite, sphene, spinel, and anatase are also present. The grains are much worn. Similar but unworn heavy minerals occur in a belt of garnetiferous staurolite schist and gneiss, kyanite schist and gneiss, and sillimanite schist and gneiss of Precambrian age exposed east of Gingin. These old gneisses were tentatively suggested to be the

TABLE 28.—*Mineralogical composition of monazite-bearing concentrates from Permian sedimentary rocks in the vicinity of Wandagee, Western Australia*

[Modified from mineralogical analyses by Higgins and Carroll (1940, p. 149); P, present]

Sample and locality	Concentrate [1]	Heavy minerals (frequency percent)															
		Magnetite	Ilmenite	Limonite and leucoxene	Zircon	Tourmaline	Rutile	Anatase	Brookite	Garnet	Sphene	Monazite	Chlorite	Mica	Epidote	Staurolite	Spinel
1. North side of Minilya River.	0.71	P	5	24	39	2	4	P	--------	20	1	1	--------	------	P	--------	P
2. North side of Carnarvon Road.	Tr.	P	3	19	56	4	4	1	--------	5	5	2	--------	------	P	--------	--------
3. North side of Minilya River.	.55	P	3	22	50	6	9	P	P	5	5	P	P	------	--------	--------	--------
4. South side of Carnarvon Road.	.45	P	1	34	32	5	9	P	--------	14	2	P	P	------	--------	P	--------
5. North side of Minilya River.	.30	P	1	28	44	7	6	P	P	10	1	1	--------	------	P	--------	--------
6. North side of Carnarvon Road.	1.00	P	1	46	26	2	3	P	--------	14	3	1	--------	------	--------	--------	--------
7. Do	.80	P	4	40	22	5	3	P	--------	21	3	P	--------	------	--------	--------	--------
8. Do	.57	P	11	28	27	3	3	--------	--------	25	P	P	--------	1	--------	P	--------
9. North side of Minilya River.	Tr.	P	7	33	34	5	2	2	--------	13	1	P	P	------	--------	--------	--------
10. South side of Minilya River.	Tr.	P	6	26	19	6	4	1	P	35	P	P	--------	1	P	P	--------
11. North side of Carnarvon Road.	Tr.	P	1	15	40	3	5	--------	--------	34	P	P	P	P	--------	--------	--------
12. South side of Minilya River.	Tr.	P	1	17	46	1	7	P	--------	26	P	P	--------	------	P	--------	--------
13. Wandagee Hill	1.31	P	2	55	10	2	2	--------	23	1	1	2	--------	------	P	--------	P
14. Do	1.20	P	23	36	25	4	1	1	--------	P	4	3	--------	------	--------	--------	--------
15. Do	2.00	P	24	36	28	1	3	P	--------	2	2	2	--------	------	P	--------	P
16. Do	.13	P	22	30	31	4	4	P	--------	6	1	P	--------	P	P	--------	--------

[1] Expressed as weight percent of sediment from which it came.
Samples 1–8 are ferruginous, calcareous, and micaceous sandstone, rare sandy shale.
Sample 9 is calcareous fine-grained sandstone.
Sample 10 is gypsiferous shale.
Samples 11 and 12 are massive argillaceous and micaceous sandstone.
Samples 13 through 16 are coarse-grained sandstone.

source of the heavy minerals in the greensand at Poison Hill (Carroll, 1941, p. 90).

Detrital monazite has been found in the soil at Hillside (Hillside Station), Mount Francisco, and Split Rock (Split Rock Station) in the northwestern part of the State, at Perth in the southwest, and at Kookynie in the central part. At Hillside the monazite is associated with detrital quartz, feldspar, microlite, and samarskite. In the occurrence at Mount Francisco, monazite is mixed with cassiterite and tanteuxenite in clayey and gravelly soil which marks the outcrop of two pegmatite dikes in granite. Angular fragments of monazite found in the soil at Split Rock, about 13 miles north of Eleys Well (Eleys), seem to have had their source in a nearby pegmatite. The beach sand and the soils derived from limestone exposed along the coast near Perth contain well-rounded particles of monazite. Sparse grains of monazite have been detected among the heavy minerals recovered from soils around Kookynie, but the source has not been described.

Detrital monazite of unknown source has been found at Pilgangoora in the northwestern part of the State. Elsewhere in the northwest it has been discovered with garnet and ilmenite at Tabba-Tabba, with yttrotantalite at Tambourah, and at a point 10 miles south of Wodgina. In the central part of Western Australia a little monazite was found with gold at Eucalyptus, and some monazite was identified in material taken from the road between Esperance and Coolgardie about 10 miles south of Sheep Rock.

Black sand from Lake Jasper and the Donnelly River in the Nelson District contains a little monazite and kyanite but consists dominantly of ilmenite. None of these deposits seems to be a commercial source for monazite (Maitland, 1904).

Monazite is a common accessory mineral in cassiterite-bearing streams throughout Western Australia. Indeed, 8 of the 11 alluvial deposits reported by Simpson (1919, p. 5; 1952, p. 248–252) to contain monazite are tin placers. In the northwestern part of the State, monazite occurs with cassiterite in a placer about 10 miles southwest of Abydos (Abydos Homestead). Monazite is very common in the tin placers at Shaw and Cooglegong (Simpson, 1912b, p. 94; 1914, p. 42) where it is accompanied by cassiterite, fergusonite, euxenite, and gadolinite and is derived from local Precambrian pegmatites. Monazite, cassiterite, and tantalopolycrase occur in a placer at Eleys. Concentrates from the gold and cassiterite placers along Friendly Creek contain monazite. At Globe Hill monazite is concentrated with cassiterite and ilmenorutile in stream placers. Cassiterite, monazite, and columbite occur together in alluvial deposits at Moolyella. Coarse-grained cassiterite, garnet, columbite, and monazite are found in the tin placers at the southeast end of the Poona area in the Murchison gold field (Simpson, 1912b, p. 94). In the southwestern part of the State, monazite is associated with abundant zircon and cassiterite at Greenbushes. Tin-free monazite-bearing concentrates were reported from the Deep River, Manjimup, and the Swan River. Monazite makes up less than 10 percent of the concentrates from the Deep River, which consist principally of garnet, ilmenite, zircon, and a little spinel. The concentrate from Manjimup consists mainly of ilmenite and zircon but has 15 percent of monazite and some kyanite, tourmaline, garnet, rutile, gold, and spinel. Black sand from the Swan River near Perth contains a little monazite similar in size and color to that in the soil overlying the coastal limestone.

Concentrates from beach sand on the north coast of Western Australia contain 0.1 percent of monazite, 52 percent of zircon, 27 percent of tourmaline, 10 percent of opaque minerals, 4 percent of rutile, and small amounts of epidote, hornblende, topaz, and zoisite (Baker, 1957). Concentrates from Capel on the southwest coast that have a similar composition have dominant ilmenite, 0.1–1.2 percent of monazite, and small amounts of tourmaline, epidote, cassiterite, staurolite, kyanite, garnet, zoisite, corundum, and spinel (Baker and Edwards, 1956f, p. 2–5).

Small amounts of monazite are present in 5 out of 15 samples of Recent sand from beaches at Koombana Bay and the Indian Ocean near Bunbury (Carroll, 1939, p. 96–102). The beach sands at and immediately east of Bunbury overlie tholeiite lava flows of Tertiary age (table 29; samples 1, 2, 4). Elsewhere the beach sands overlie sand and clay of coastal plain formations of Recent and older age (samples 3, 5). Inland from the coastal plain are gneisses, granites, and greenstone of Precambrian age, and about 15 miles south of Bunbury sandstone of probable Permian age crops out. The heavy minerals in the beach sands, which are locally concentrated into small placers, come from these diverse sources. The abraded character of the zircon, tourmaline, kyanite, and monazite was interpreted by Carroll (1939, p. 102) to indicate that those mineral grains have passed through several cycles of sedimentation after their release from the Precambrian rocks.

TABLE 29.—*Mineralogical composition of monazite-bearing concentrates from beach sand near Bunbury, Western Australia*

[Analyst: Carroll (1939, p. 101-102). Symbols used: VA, very abundant; A, abundant; P, present; Ab, absent]

	1	2	3	4		5
Sieve fraction	+250	+250	+115	+32	+250	+250
Magnetite	VA	VA	Ab	Ab	VA	A
Ilmenite	VA	VA	A	A	VA	VA
Calcite	Ab	P	P	P	Ab	Ab
Amphibole	P	P	A	P	P	P
Tourmaline	Ab	Ab	Ab	P	P	Ab
Leucoxene	P	P	P	P	P	Ab
Garnet	P	P	P	P	P	Ab
Epidote	P	P	P	P	P	Ab
Kyanite	Ab	Ab	P	P	P	Ab
Zircon	P	A	P	P	A	A
Rutile	P	P	P	P	P	P
Monazite	P	P	P	P	P	P
Sillimanite	Ab	P	Ab	Ab	Ab	Ab
Sphene	Ab	P	Ab	Ab	Ab	P
Apatite	Ab	Ab	Ab	Ab	P	Ab
Pyroxene	Ab	P	Ab	Ab	Ab	Ab
Spinel	Ab	Ab	Ab	Ab	Ab	P
Topaz(?)	Ab	P	Ab	Ab	Ab	Ab

1. Shore of Koombana Bay 1.6 miles east-northeast of the center of Bunbury.
2. Shore of Koombana Bay 1 mile east of the center of Bunbury.
3. Shore of the Indian Ocean 0.6 mile southwest of the center of Bunbury.
4. Shore of the Indian Ocean 0.4 mile southwest of the center of Bunbury.
5. Shore of Koombana Bay 2.1 miles northeast of the center of Bunbury.

The composition of placer monazite from Western Australia has been recorded by Simpson (1912a, p. 45–47; 1912b, p. 95; 1914, p. 43; 1919, p. 5) and Wylie (1950, p. 165). A complete analysis and three partial analyses of monazite from tin placers at Moolyella in the Pilbara gold field, where the monazite comes from pegmatite intruded into Precambrian metasedimentary rocks, greenstones, and unmetamorphosed sediments, disclose 5.02–5.24 percent of ThO_2.

Chemical analyses, in percent, of monazite from tin placers at Moolyella, Western Australia

[Analysts: 1-3, J. H. Brooking; 4, J. C. H. Mingaye]

	1[1]	2	3	4
Ce_2O_3	33.06	} 65.41	65.34	61.31
(La, Nd, Pr)$_2O_3$	30.21			
Y_2O_3	.14			
ThO_2	5.03	5.17	5.24	5.02
UO_2	None			
Fe_2O_3	2.21			
Al_2O_3	.44			
CaO	.90			
MgO	.21			
PbO	Trace			
P_2O_5	26.70			
SiO_2	1.22			
H_2O	.59			
Total	100.71			

[1] Specific gravity, 5.26.

In the same general area at Cooglegong placer, monazite derived from pegmatite contained from 3.80 to 5.93 percent of ThO_2 in three analyses. A complete and a partial analysis showed the following percentages of thorium oxide and a specific gravity of 5.30 for the monazite:

[Analysts: *A*, Simpson (1919, p. 5); *B*, J. H. Brooking (in Simpson, 1919, p. 5)]

	Percent *A*	Percent *B*
Ce_2O_3	31.10	} 53.19
(La, Nd, Pr)$_2O_3$	34.26	
Y_2O_3	.04	
ThO_2	3.80	4.38
UO_2	Trace	
Fe_2O_3	.42	
Al_2O_3	.64	
CaO	.34	
MgO	Trace	
PbO	Trace	
P_2O_5	26.89	
SiO_2	1.96	
H_2O+	.58	
Total	100.03	

An analysis of the rare earths and thorium oxide in Cooglegong placer monazite disclosed the following percentage of thorium oxide:

[Analyst: Wylie (1950, p. 165)]

	Percent
Ce_2O_3	28.6
La_2O_3	13.1
Nd_2O_3	11.9
Pr_2O_3	3.52
Sm_2O_3	3.01
ThO_2	5.93

NEW ZEALAND

Detrital monazite is widely distributed in small amounts in unconsolidated and consolidated sedimentary rocks on South Island and Stewart Island, New Zealand, but it is uncommon on North Island (Henderson, J., 1924, p. 14; Morgan, 1927, p. 70; Hutton, 1950, p. 667–670; Davidson, 1953, p. 75).

Analyses of two samples of monazite concentrates from New Zealand were given by Hutton (1950, p. 668). One concentrate, *A*, contained 85 percent of monazite and 15 percent of a mixture of grains of zircon, cassiterite, and ilmenite and had a specific gravity of 5.26. The other concentrate, *B*, contained monazite plus about 6 percent of a mixture of grains of gahnite, zircon, and intergrown ilmenite-titanhematite and had a specific gravity of 5.23. The analyses of the concentrates were recalculated by Hutton to 100 percent of monazite and showed the following percentages of thoruim oxide; the monazite is, therefore, of commercially acceptable tenor:

[Analyst: F. T. Seelye (in Hutton, 1950, p. 668)]

	Percent A	Percent B
Ce_2O_3	22.95	28.43
$(La, Nd, Pr, Sm)_2O_3$	28.28	31.17
$(Gd, Y)_2O_3$	4.28	2.32
ThO_2	5.32	5.47
U_3O_8	1.23	.00
P_2O_5	27.12	28.57
SiO_2	2.46	1.18
Al_2O_3	------	[1] 1.03
Fe_2O_3	2.88	[2] .93
$(Ta\ Nb)_2O_3$	5.48	-------
CaO	------	.82
MgO	------	.08
Total	100.00	100.00

[1] The high value for Al_2O_3 may result from included sillimanite (Williams, 1934, p. 354).
[2] $FeO+Fe_2O_3$.

A. Ngahere gold dredge, Grey River, South Island, on south flank of Paparoa Range.
B. Placer at Mudtown, Port Pegasus district, Stewart Island.

Monazite has not been obtained from placer concentrates in New Zealand, although recovery was considered in 1946 at some gold dredges on South Island (Chem. Eng. and Mining Rev., 1946, p. 53). In South Island the gold placers worked by the Atarau, Blackball, Grey River, Ngahere, Red Jacks, and Slab Hut dredges in the drainage basin of the Grey River are monazite bearing (Hutton, 1950, table 19), but monazite has not been recovered. Other dredges on South Island that work monazite-bearing gravels but have not recovered monazite are the Barrytown dredge between the mouth of the Grey River and Charleston and the Arahura, Kaniere, Rimu, and Gillespies Beach dredges south of the mouth of the Grey River. No monazite has been produced from the placers on Stewart Island or from the iron sands along the Taranaki coast of North Island. The New Zealand Geological Survey has considered the monazite to be too sparse to be worth the cost of recovery (Henderson, John, 1924, p. 14).

SOUTH ISLAND

Early bulletins of the New Zealand Geological Survey mentioned monazite in cassiterite-bearing gold placers along the west coast and in the northwestern part of South Island in the Westland and Nelson Divisions. Detrital monazite was said (Ross, Kenneth, 1906, p. 12) to be a doubtful constituent of sluice-box concentrates from the Waimangaroa River and to be present in glaciolittoral deposits south of Whareatea River (Wareatea) where it is associated with rhodonite, zircon, and platinum. Detrital monazite was reported (Marshall, 1908, p. 109) in small amounts in sand at Greymouth and was seen with cassiterite, gold, and chromite at Montgomery's Terrace sluicing claim northeast of Greymouth near Blackball where it was reported by Morgan (1911, p. 91) to have come from granitic and gneissic rocks in the Paparoa Range to the north of the placer. A concentrate of unspecified mineral composition from a sluicing claim near Greymouth was shown (MacLaurin, 1912, p. 23) to contain 0.62 percent of ThO_2 and 4.68 percent of RE_2O_3. In the Reefton area northeast of Greymouth between the Paparoa and Victoria Ranges, monazite, zircon, and garnet are in all the streams (Henderson, John, 1917, p. 224). North of Greymouth in the drainage basins of the Buller and Mokihinui Rivers monazite occurs with gold in placers at Bradshaw (New Zealand Mines Rec., 1903, p. 128; Engineer, 1904; Morgan, 1913, p. 117–118) and Fairdown, and small amounts of monazite were discovered in black sand along the coast (Morgan and Bartrum, 1915, p. 123). A concentrate from Bradshaw contained 0.2 percent of ThO_2 and 0.42 percent of RE_2O_3 (Fry, 1905, p. 27). Monazite in a concentrate containing garnet, zircon, magnetite, and gold has been reported from Aorere in the Collingwood district at the extreme northwest end of South Island (MacLaurin, 1913, p. 24; Morgan and Bartrum, 1913, p. 21). This concentrate contained 0.6 percent of RE_2O_3 plus ThO_2. A concentrate from the same area, possibly the same concentrate, was chemically analyzed and found to contain rare earths, but the minerals were not described (Ongley and Macpherson, 1923, p. 43). Gravel in an unspecified gold-dredging area on the west coast of South Island has recently been estimated to contain 0.0005 percent of monazite which has 4.93 percent of ThO_2 and 1.15 percent of U_3O_8 (Chem. Eng. and Mining Rev., 1946, p. 53). Methods for recovery of the monazite as a byproduct of gold dredging were being investigated in 1946.

The distribution of monazite and other heavy minerals in South Island was the subject of a comprehensive study by Hutton (1950), and the subject of short reports by F. J. Turner (1943), and by Hutton and Turner (1936). The studies showed that small amounts of detrital monazite are common in most sediments on the Island except near Lake Manapouri and the Waiau Valley in Southland, in most of Otago, and at the Wainui Inlet.

Monazite was present in only two out of nine samples of Tertiary sandstone exposed near Lake Manapouri, and in these monazite was a scarce accessory mineral. Monazite was found in concentrates from a coarse sandstone exposed 0.25 mile east of Circle Cove, Lake Manapouri, and in the heavy fraction from a coarse sandstone at Freestone Hill near the lake. The probable source of the few grains of monazite in the two samples was the Fiordland complex of gneisses and schists (Hutton and Turner, 1936, p. 256–262).

Monazite is absent from Teritary sediments in the Waiau Valley in Southland where the sediments have been derived from norites (Hutton and Turner, 1936, p. 262–263). Alluvium eroded from weathered gabbro and ultramafic rocks has been the source of gold at the Round Hill placers along Ourawera Stream in the Longwood district of Southland (Macpherson, 1938, p. 743). Monazite was reported by Macpherson as probably accompanying the ilmenite, magetite, green hornblende, zircon, and garnet with which the gold is associated, but its occurrence is uncertain.

A few grains of monazite were discovered by Hutton and Turner (1936, p. 263–265) in one sample of Tertiary sandstone from Bob's Cove, Lake Wakatipu, northwestern Otago.

The main monazite-bearing sediments on South Island are alluvial and fluvioglacial deposits in the drainage basin of the Grey River and littoral and stream deposits along the coastal plain from Cape Foulwind to Westport (Hutton, 1950, p. 697). Heavy-mineral concentrates from this region are characterized by zircon, monazite, xenotime, and cassiterite.

Hutton examined numerous specimens of granite, gneiss, and schist from the northwestern part of South Island, including rocks from the Paparoa and Victoria Ranges, for monazite. He found the monazite, however, to be almost wholly restricted to biotite gneisses of middle and upper amphibolite facies. Concentrates from the granites and schists contained no monazite except for rare samples in which one or two grains were observed. The main exposures of monazite-bearing gneiss are along the west coast south of Charleston, at the mouth of the Nile River, and in the upper reaches of the Otututu River (Hutton, 1950, p. 699). Migmatites in the Charleston-Fox River area contain monazite (Hutton, 1950, p. 696). These high-rank metamorphic rocks seem to have been the main source of monazite in sediments of Quaternary, Tertiary, and Triassic to Jurassic age in this part of South Island. Erosion of the gneisses and sediments provided the monazite in the Recent stream and beach sands. Sand from the beach at Charleston was said (Donovan, 1930, p. 25) to contain considerable garnet, smaller amounts of monazite and zircon, and a trace of gold and silver.

The distribution of monazite along the coast of South Island southwest of Greymouth, where it has been found in four placer districts and occurs as an accessory mineral in concentrates panned from stream gravels (Hutton, 1950, table 19), seems to be related more to sedimentary recycling of detrital monazite through an involved sequence of geomorphic and glacial events, than to several independent primary sources. Independent sources, such as the Fiordland gneisses at Lake Manapouri (Hutton and Turner, 1936, p. 256–262), seem to contribute little monazite to the sediments. The sources of the monazite found in small amounts elsewhere on South Island have not been discussed.

Monazite-bearing auriferous cassiterite placers are found at the extreme south end of Stewart Island in the Port Pegasus district (Williams, 1934, p. 344–354). The roof of an extensive granitic batholith which invaded amphibolite, calc-silicate hornfels, biotite-muscovite schist, and quartzite is exposed in the southern part of Stewart Island. In the Port Pegasus district only the granite, schist, and quartzite crop out, and the steeply dipping metamorphic rocks form the crest of a mountainous ridge known as the Tin Range. Cassiterite-wolframite lodes cut the quartzite and biotite-muscovite schist in the Tin Range. Monazite has not been observed in the lodes, nor has it been seen in thin sections of the rocks in the Port Pegasus district, but detrital monazite is common in concentrates from the eluvial and alluvial placers. The grains of detrital monazite ordinarily are slightly abraded euhedral crystals of prismatic habit. Many grains are clouded with what Williams (1934, p. 354) assumed to be thorite dust. Some grains of monazite include interwoven fibers and silky needles of sillimanite, but sillimanite itself is found in few of the concentrates. It occurs as needles in monazite and quartz and as discrete fragments. Williams concluded that the placer monazite was derived from the schists and that it was formed in the schists from fluids that invaded the schists to produce the cassiterite-wolframite lodes.

NORTH ISLAND

A little monazite has been observed in sediments that underlie some of the detrital black iron sands on the west coast of North Island. Magnetite sands are found along the Taranaki coast of North Island from Patea in the south to New Plymouth in the north, and scattered deposits have been observed as far north as the Manakau Heads near Auckland (Wylie, 1937, p. 227). The largest deposits are at Patea, New Plymouth, and Manakau Heads. The principal minerals are magnetite, ilmenite, quartz, augite, hornblende, and diopside. Zircon is scarce. Small traces of cerium oxide have been noted in some analyses of the ores, but the location and mineralogy of the cerium oxide-bearing samples were not given (Wylie, 1937, p. 228). Mineralogical studies of the sand at Patea (Hutton, 1940, p. 193B–198B) and New Plymouth (Hutton, 1945, p. 297–302) disclosed that monazite was present only in the southern part of the Taranaki coast at Patea. Even at Patea the terrace, beach, and dune deposits of titaniferous iron sands do not contain monazite. Rather, two sedimentary units below the iron sands, called the Patea silts and the Hawera series, are monazite bearing. Monazite is a scarce mineral in the silts and constitutes less than 5 percent of the heavy minerals from the Hawera series.

The small number of reported occurrences of monazite on North Island may possibly be related to the absence of the monazite-bearing gneisses seen on South Island (Ongley, 1947, map of North Island). The absence of present exposures of these gneisses on North Island, however, is unlikely to be fully responsible for the scarcity of monazite there. Several lines of geologic evidence have been developed to show that gneissic rocks and granites like those in the northwestern part of South Island lie submerged off the west coast of North Island or are buried in the center of North Island. Thus, Wellman (1948, p. 1–2) commented that bouldery detritus found in Tertiary and Mesozoic conglomerates on North Island and derived from sources now submerged off the west coast of the island seems to have come from the same group of rocks in which the monazite-bearing gneiss of South Island is found. Hutton (1940, p. 204B) wrote that despite the possibility the monazite at Patea may have been derived from the gneisses in the northwestern part of South Island when Cook Strait was closed in Teriary time and streams flowed into what is now the western part of North Island, there is strong evidence that a granitic source may be concealed under graywackes in the center of North Island or sunk off the west coast. Hutton stated (1940, p. 204B) "it is clear that acid intrusives and metamorphic rocks may have at times been exposed in the North Island, and hence the source of many of the minerals in the heavy residues may well have been, perhaps after rewash from previous sediments, a North Island metamorphic and intrusive terrain." That monazite was not found in sediments on North Island may not reflect as much the absence of gneissic and granitic terrane as it reflects the sparseness of monazite in the plutonic sources in or adjacent to North Island.

ANTARCTICA

The beach sands of a small island about 110 miles north of Cape Royds and near the volcanic Mount Erebus were said to contain detrital monazite (Fitzau, 1909, p. 480; Österreichische Zeitschrift für Burgund und Hüttenwesen, 1909). Seemingly the monazite is not of local origin. Traces of monazite occur between Cape Adare and Gaussberg (Mining and Eng. Rev., 1911, p. 192).

Monazite is an accessory mineral in kyanite-biotite gneiss at Garnet Point, Adélie Coast (Mawson, 1940, p. 397). It is an uncommon accessory mineral in cataclastically metamorphosed and recrystallized granite boulders in morainal deposits at Cape Denison, Adélie Coast (Kleeman, 1940, p. 239–241). Monazite is a common minor accessory mineral in boulders of granite gneiss with primary flow banding in the same morainal deposits (Kleeman, 1940, p. 249–250). Other accessory minerals in the granite gneisses are xenotime, zircon, magnetite, sphene, and allanite. Xenotime and allanite are each more common than monazite in the granite gneiss fragments from the moraines at Cape Denison. Rocks in the moraines resemble bedrock at Cape Denison.

Fragments of pyroxene marble from the moraines at Commonwealth Bay contain possible monazite as an accessory mineral (Glastonbury, 1940, p. 307–308). The marble consists mainly of calcite with some black pyroxene altering to epidote, some forsterite pseudomorphically replaced by serpentine, and some microcline. Minor constituents include scapolite, sphene, graphite, apatite, zircon, magnetite, and possible monazite. The marble formed at very high metamorphic grade from limestone.

NORTH AMERICA

The first sources of monazite that were important in world commerce were the fluvial placers in the Piedmont province of North and South Carolina. These deposits were mined from 1887 to 1911 and again from 1915 through 1917. Other exploited sources of monazite in the United States are beach placers in Florida, placers in Idaho, and a fluvial deposit in the Coastal Plain of South Carolina. Large resources of monazite have been discovered in fossil placers in sandstone of Late Cretaceous age in the San Juan Basin of Colorado and New Mexico but have not been exploited. Very large resources of monazite doubtless exist in the sedimentary rocks of the Atlantic and Gulf Coastal plains of the Southeastern United States and along the gulf coast of Mexico. Little or no monazite has been found in Central America or on the islands of the Caribbean Sea. A large deposit of bastnaesite in California, similar rare-earth-bearing deposits in Canada, and thorium-bearing veins in the Western United States and Canada assure sources of rare-earth metals and thorium independent of the presently known supplies of monazite.

CUBA

Monazite was reported from Finca Parnaso, Victoria de las Tunas, and Finca Magdalena, Caney, in Oriente Province and from Ciego de Ávila in Camagüey Province, but the mode of occurrence was not described (Roig, 1928, p. 177).

DOMINION OF CANADA

Canada was deficient in monazite in 1933, and its needs were met by imports (Wilson, A. W. G., 1933, p. 70). Even as late as 1956, no thorium ore was produced, but there were minor resources of the metal (Janes, 1956, p. 14). Rare-earth minerals were thought to be more abundant (Mining Journal, 1925b).

Inasmuch as nearly all Canada was glaciated in Pleistocene time, economically important residual or placer deposits of monazite are unlikely to be found (Ellsworth, 1932a, p. 108). A few preglacial gold placers in British Columbia were protected from glaciation, as were parts of Yukon Territory, but no significant placers have been found, although several monazite-bearing concentrates have been reported. Since the retreat of the last glacial ice, insufficient time has elapsed for residual deposits or stream placers to form (Ellsworth, 1932a, p. 109). Fossil placers, many of great antiquity, have proved to be the main source of monazite.

BRITISH COLUMBIA

Small amounts of monazite in concentrates from gold placers were noted along the North Thompson River in the early 1900's by Day and Richards (1906b, p. 1220–1221). Molybdenite-uraninite veins at Hazelton were said to contain monazite and allanite (Heinrich, 1958, p. 271). Although monazite was reported from other localities in British Columbia, specific deposits were not cited, and deposits were said to be too small to be minable (James and others, 1950, p. 255; Steacy, 1953, p. 549). Monazite is a sparse accessory mineral in concentrates from the Quesnel River about 8 miles upstream from its confluence with the Fraser River (Lang, 1952, p. 46). Placer deposits on Bugaboo Creek were mentioned as a possible source for thorium, but it is not certain from the reference if the thorium mineral is monazite (Janes, 1956, p. 14).

MANITOBA

The monazite-bearing pegmatite on the Huron claim in the Winnepeg River area of southeastern Manitoba has frequently been cited because it contains monazite and other scarce minerals, but the monazite is only a minor constituent of the dike (DeLury and Ellsworth, 1931, p. 569–570; Ellsworth, 1932a, p. 164–167; Lane, 1938b, p. 130–131; Lang, 1952, p. 116; Cumming and others, 1955, p. 64). According to DeLury and Ellsworth (1931), the pegmatite on the Huron claim is one of several dikes and sills that occur in plutonic igneous rocks and roof pendants of metavolcanic and metasedimentary rocks in an area extending from Shoal Lake, which is near the Ontario border, as far north as the Grass River. These pegmatites are most abundant in the area extending from the Oiseau and Winnipeg Rivers southward to West Hawk Lake and Falcon Lake; and several pegmatites are known near Island Lake. The pegmatite characteristically contains some or all of a large group of minerals: spodumene, lepidolite, amblygonite, beryl, topaz, cassiterite, molybdenite, bismuthinite, bismuth, apatite, monazite, columbite, tantalite, and uraninite. Monazite is more abundant than uraninite, and both occur as crystals and grains embedded in feldspar; but the monazite is apparently not very common in these pegmatites.

The Huron claim is 0.5 mile inland from the southeast shore of the Winnipeg River about 9–10 miles upstream from Pointe du Bois (DeLury and Ellsworth, 1931, p. 569). This pegmatite is in a roof pendant of andesite schist. Its strike conforms to the eastward strike of the schist which is parallel to the trend of a contact of the schist with granite about 1,500 feet north of the pegmatite. Monazite from the Huron claim was analyzed several times for age determinations. Microchemical analysis by Hecht and Kroupa (1936, p. 98) disclosed the following percentage of thorium oxide:

	Percent		*Percent*
RE_2O_3	46.28	MgO	0.10
ThO_2	14.42	PbO	1.30
U_3O_8	.14	MnO	.71
P_2O_5	22.46	Insoluble residue	.50
SiO_2	8.50	H_2O-	.69
Al_2O_3	.52	H_2O+	1.24
Fe_2O_3	.95		
CaO	3.23	Total	101.04

An analysis by Muench (1950, p. 131) showed 15.63 percent of ThO_2 in monazite from the Huron claim.

Monazite was said to be present in a large pegmatite dike in the Bird River area of Manitoba (Mining World, 1958). In addition to the monazite, the dike reportedly contains beryl, topaz, columbite, tantalite, and cesium and rubidium minerals.

NEWFOUNDLAND

Poorly sorted, stratified sand of Pleistocene age that is exposed in a raised delta of a small stream a mile inland from Nain, Labrador, is monazite bearing (Martens, 1929, p. 23). The deltaic sediments were derived from anorthosite, granite, and gneiss. About 9 percent of the sand consists of heavy minerals, which in one sample were as follows:

[Analyst: Martens (1929, p. 31)]

	Frequency percent		Frequency percent
Black opaque minerals	20	Rutile	Trace
Garnet	7	Biotite	0.2
Hornblende	31	Monazite	.2
Hypersthene	19	Sillimanite	.5
Augite	14	Tourmaline	Trace
Epidote	2	Actinolite	.2
Sphene	.2		
Apatite	4	Total	99.0
Zircon	.7		

NORTHWEST TERRITORIES

Fine-grained monazite occurs with uraninite in dolomite at the east end of McLean Bay on Stark Lake (Lang, 1952, p. 65). The locality is 16 miles east of Snowdrift in the East Arm area of Great Slave Lake. Two radioactive zones, 6 feet and 10 feet wide respectively, are present. They are stained reddish brown by hematite. Average abundances of U_3O_8 and ThO_2 in the most radioactive parts of the zones were said to be about 0.005 and 0.025 percent, respectively.

Monazite is a minor constituent in small well-sorted beach placers on the south shore of Yamba Lake (Folinsbee, 1955, p. 7). Magnetite, ilmenite, and almandite are the most abundant heavy minerals. A very large suite of minor minerals is present and includes andalusite, apatite, brookite, epidote, hornblende, kyanite, olivine, pyroxene, rutile, scheelite, sphene, sillimanite, spinel, staurolite, tourmaline, zircon, and monazite. The immediate source of the heavy minerals is esker sand on the south shore of the lake, but the original source was gneiss and migmatite. The migmatite consists of oligoclase, quartz, and biotite; accessory monazite, rutile, and zircon; local accessory cordierite; and patchily distributed sillimanite, kyanite, graphite, and almandine garnet (Folinsbee, 1955, p. 9–10). Granitelike lenticular masses that are about 1 foot long and 2 inches wide and that are composed of alkalic feldspar, quartz, muscovite, and excessively scarce monazite occur in the migmatite. A biotite-rich phase of the migmatite near Yamba Lake contains 0.01 percent of monazite.

The beach placers on the lake are about 50–100 feet long, 3–10 feet wide, and 6 inches thick; thus, the total amount of black sand is small, and monazite makes up only 1 percent of the concentrate. Monazite in the placers has the same crystal habit, size range, and physical properties as the monazite in the migmatite. Its specific gravity is 4.91–4.94 ±0.05, and according to spectrochemical analysis by G. M. Gordon it contains 1.7 percent of ThO_2 (Folinsbee, 1955, p. 15). The Yamba Lake placer monazite was reported to contain 4.8 percent of ThO_2 and 0.25 percent of U_3O_8 (Gottfried and others, 1959, p. 21).

Apparently several other monazite placers of uneconomic size and tenor are known in the Northwest Territories (James and others, 1950, p. 255), but specific localities have not been published.

NOVA SCOTIA

Monazite occurs in a cassiterite-bearing pegmatite dike in light-gray granite on the Reeves farm 3 miles west of New Ross, Lunenburg County (Spence, 1930, p. 491; Ellsworth, 1932a, p. 255–256). The dike is about 8 feet wide and consists of feldspar, quartz, a little mica, and accessory amblygonite, durangite, cassiterite, scheelite, wolframite, lepidolite, monazite, and beryl. Monazite was also found as a minor accessory mineral in the granite.

A pegmatite at Lake Ramsay in the New Ross area contains monazite and gummite but is not certainly known to be related to cassiterite-bearing pegmatite dikes in the area (Lang, 1952, p. 155).

Monazite is present as an accessory mineral in granite at localities 3.8 miles east of Port Mouton, 0.5 mile east of Albany Cross, and near Shelburne (Hurley and Fairbairn, 1957, p. 942). The monazite from the Port Mouton area contains 4.4 percent of ThO_2, that from Albany Cross 2.9 percent, and that from Shelburne 8.6 percent.

ONTARIO

Pegmatite dikes consisting of graphic intergrowths of quartz and microcline and containing muscovite, biotite, garnet, and molybdenite in Dickens Township, Nipissing District, have been the source of museum specimens of monazite since the early 1920's (Ellsworth, 1924, p. 261–262; 1932a, p. 192–195; 1932b, p. 19; Mining Jour., 1925b; Lang, 1952, p. 142; Cumming and others, 1955, p. 53). At least three dikes in the area are known to be monazite bearing. They are located in lot 27, concession 5; lot 9, concession 13; and lot 19, concession 1. The first of these occurrences was mined for feldspar and mica in 1943, and the last was being worked for feldspar in 1952 (Lang, 1952, p. 142). None is a commercial source of monazite.

These pegmatite dikes intrude garnetiferous granite gneiss, biotite schist, hornblende schist, and mafic intrusive rock (Ellsworth, 1932a, p. 192–195). Monazite in the pegmatite dike in lot 9, concession 13, occurs as flat crystals that range from reddish brown to black. The monazite, which had a specific gravity of 5.27, was black (Ellsworth, 1932a, p. 264; 1932b, p. 21, 26) because of finely divided carbon disseminated in a normal monazite having the following composition:

[Analyst: Ellsworth (1932a, p. 264; 1932b, p. 21, 26)]

	Percent		Percent
Ce_2O_3	22.63	CaO	0.35
$(La, Di)_2O_3$	34.63	MgO	.02
$(Y, Er)_2O_3$	4.66	PbO	.33
ThO_2	7.32	H_2O-	.06
U_3O_8	.32	H_2O+	.34
P_2O_5	27.89	C	Trace
SiO_2	1.54		
Al_2O_3	<.10	Total	100.27
Fe_2O_3	.08		

Ellsworth (1932a, p. 195) reported that several other pegmatite dikes in the Dickens Township area contain monazite, but that they also are mineralogical localities, not commercial sources.

Monazite occurs sparingly in a molybdenite-bearing biotite pegmatite at the Cameron property 2 miles east of the south end of Vermilion Lake and about 15 miles north of Kenora (Lang, 1952, p. 118). At another locality about 1.5 miles east of Vermilion Lake and north of Kenora, biotite-rich zones of a pegmatite dike in greenstone contain monazite (Lang, 1952, p. 121).

Monazite is a minor accessory mineral in a pegmatite dike in lot 23, concession 15, Lyndoch Township, Renfrew County (Ellsworth, 1932a, p. 228; Freeman, 1936, p. 30; Lang, 1952, p. 146). The dike, which occurs in gneissic red granite, consists of quartz and coarse-grained microcline that is partly replaced by albite, muscovite, beryl, tourmaline, fluorite, magnetite, zircon, columbite, lyndochite (thorium calcium euxenite), garnet, and monazite. This pegmatite is 20 feet thick and more than 100 feet long. Although the pegmatite was mined for beryl in a small way in 1926, only a few crystals of monazite have been observed in it. The largest crystals were about 2 inches across by 0.5 inch thick.

Monazite apparently occurs with euxenite and columbite in a pegmatite mined for feldspar in Conger Township a few miles south of Parry Sound (Lang, 1952, p. 141; Janes, 1956, p. 14). A body of pegmatite in Pitt Township was also reported to contain a little monazite (Lang, 1952, p. 150).

Sheetlike pyritic uranium deposits in gently dipping quartz-pebble conglomerates and quartzites in the Blind River region contain yellow, orange, brown, green, .and amber grains of monazite (Traill, 1954; Stockwell, 1957, p. 109; Davidson, 1959b, p. 1319; Mair and others, 1960, p. 341–343). The quartzites and conglomerates are 1–3 feet thick and are at the base of the Mississagi quartzite of Huronian age that unconformably overlies granite and greenstone. The Huronian sedimentary rocks are slightly metamorphosed and contain argillite and a minor amount of limestone in addition to the conglomerate and quartzite. In the Blind River region the Mississagi quartzite is 1,500–3,500 feet thick.

Monazite, uraninite, and brannerite occur in the matrix of the conglomerate as discrete, very fine grained particles. Zircon, rutile, magnetite, anatase, thorogummite, galena, chalcopyrite, pyrrhotite, and cobaltite are present in small amounts. Most of the grains of monazite are round, but a few are crystal fragments. Monazite is highly erratic in distribution in the conglomerate, being fairly common at one place and almost absent elsewhere. Gold is also irregularly distributed. Brannerite and uraninite are the major ore minerals; immense reserves were reported (Stockwell, 1957, p. 109).

Sedimentary and hydrothermal hypotheses for the origin have been proposed, but an original detrital origin possibly modified by low-grade dynamothermal metamorphism may best explain the origin and distribution of monazite in the deposit. In this area, a study of the composition of the monazite at different places in the deposit would help explain the origin.

Clay of Pleistocene age in the Don valley, Toronto, contains a few scarce grains of monazite in a complex suite of heavy detrital grains (Derry, 1933, p. 114, 116). It is not a typical mineral of the clay. The monazite is associated with augite, diopside, dolomite, enstatite, epidote, dominant garnet and hornblende, hypersthene, kyanite, leucoxene, magnetite, ilmenite, sphene, topaz, zircon, and zoisite.

One out of three samples of beach sand from the shore of Lake Ontario just east of the entrance to Toronto Harbor contained detrital monazite (Trainer, 1930, p. 194–195). The beach sand formed from material eroded from cliffs of glacial and interglacial sedimentary deposits at Scarborough Heights east of Toronto. A garnet-rich layer of the beach sand contained the monazite; a mineralogical analysis of the heavy-mineral concentrate of this layer follows:

[Analyst: Trainer (1930, p. 195)]

	Percent
Ilmenite	3.9
Garnet	56.0
Augite	4.8
Pyroxene	4.8
Leucoxene	1.6
Hornblende	27.0
Monazite	1.6
Total	99.7

QUEBEC

The earliest descriptions of monazite in Quebec were references to masses and crystals in pegmatite at the Villeneuve mica mine in Villeneuve Township, Papineau County (Hoffman, 1887; 1889, p. 92; 1890, p. 184;

Genth, 1889, p. 203; American Naturalist, 1889; Goodwin, 1897, p. 218; Obalski, J., 1906, p. 72). The pegmatite is about 150 feet wide and strikes northeastward parallel to the foliation of the enclosing garnet gneiss. It consists of quartz, microcline, albite, muscovite, black tourmaline, spessartite, and lesser amounts of apatite, fluorite, zircon, beryl, uraninite, monazite, and cerite (Ellsworth, 1932a, p. 240–241; Dresser and Denis, 1949, p. 437; Spence, 1930, p. 431; Lang, 1952, p. 154). Villeneuve mine was opened for muscovite in 1884, and about 1887 a rounded mass of reddish-brown monazite weighing 12.25 pounds was discovered. This mass had a specific gravity of 5.138 (Hoffman, 1887) and was said to have been slightly altered. A specimen of monazite having specific gravity of 5.233 from the Villeneuve mine was analyzed and was found to have the following composition:

[Analyst: Genth (1889, p. 203; see also Johnstone, 1914, p. 58, and Imp. Inst. [London], 1914a, p. 60)]

	Percent		Percent
Ce_2O_3	24.80	Fe_2O_3	1.07
$(La, Di)_2O_3$	26.41	CaO	1.54
$(Y, Er)_2O_3$	4.76	MgO	.04
ThO_2	12.60	H_2O	.78
P_2O_5	26.86		
SiO_2	.91	Total	99.77

Except for mineralogical samples this mine is not a source of monazite.

In the adjoining West Portland Township, monazite has been found as large well-formed tabular crystals as much as 6 inches across in a granitic pegmatite dike that also contains euxenite and allanite (Spence, 1930, p. 431). The dike, which occupies an area about 30 by 75 feet, is emplaced in biotite gneiss. The monazite and euxenite are present in about equal amounts and are associated with abundant black tourmaline in albite-rich zones in the pegmatite (Spence and Muench, 1935, p. 725–728). Most of the monazite is severely weathered, thus, paragenetic relations are obscure, but the possibility exists that some of the monazite was altered to allanite prior to the weathering. Possibly the original alteration was related to metamorphism during the Taconic orogeny (Spence and Muench, 1935, p. 728, 731). Three determinations by Muench (in Spence and Muench, 1935, p. 732) disclosed 3.39, 3.38, and 3.55 percent of ThO_2 in the monazite, and the following complete analysis showed 4.25 percent of ThO_2 and 0.11 percent of U_3O_8, which was determined separately:

[Analyst: Friedrich Hecht (in Spence and Muench, 1935, p. 732; see also Cumming and others, 1955, p. 56)]

	Percent		Percent
RE_2O_3	62.09	CaO	0.99
ThO_2	4.25	MgO	.56
P_2O_5	27.39	H_2O+	.60
SiO_2	3.21		
Al_2O_3	.69	Total	101.88
Fe_2O_3	2.10		

The dike was mined for feldspar and was reported to have been the source of about 20 pounds of monazite during the middle or late 1930's (Lang, 1952, p. 154).

Pegmatite exposed 6 miles northwest of Lepine Depot north of Maniwaki was said to contain monazite and allanite (Lang, 1952, p. 152, 153).

Monazite is a minor accessory mineral in the Amherst graphite deposits about 12 miles from St. Jovite (Cirkel, 1911, p. 109–115). The area is underlain by gneiss and crystalline limestone of the Grenville Series intruded by pyroxenite, granite, diorite, and diabase. Crystalline graphite is found in veins that consist of about 75 percent of intermixed graphite, orthoclase, perthite, microcline, albite, and anorthite and 25 percent of mixtures of augite, hypersthene, wollastonite, calcite, and quartz. Fine-grained apatite, sphene, and garnet are commonly enclosed in the feldspar. Scattered grains, small crystals, or minute scales of scapolite, zircon, muscovite, pyrite, leucoxene, biotite, monazite, and magnetite occur as sparse inclusions in the feldspar and pyroxene. Inasmuch as the graphite also occurs as clean, perfect crystal inclusions in the feldspar, Cirkel (1911) inferred that graphitic carbon was present when the veins formed. The veins may be pegmatitic deposits. Monazite from this unusual occurrence has not been analyzed.

Monazite is a minor accessory mineral in a pegmatite dike exposed at Lac Pied des Monts in De Sales Township, Charlevoix County, about 18 miles northeast of Murray Bay (Dresser and Denis, 1949, p. 437–438). The dike is 15–20 feet thick and consists of microcline, albite, quartz, abundant biotite, and some muscovite. Along with the monazite, small quantities of zircon, uraninite, and thucholite are present.

Sparse accessory monazite occurs in skarn at the Calumet Uranium Mines, Ltd., holdings in Grand-Calumet Township (Shaw, 1958, p. 30–32). The skarn consists mainly of calcite and contains small amounts of diopside, lithium mica, chondrodite, uranoan thorianite, uranothorite, and monazite. A bulk sample of the skarn contained 0.10 percent of U_3O_8 and 0.15 percent of ThO_2. Apparently very little of the thorium is in the monazite.

Marine sand of Pleistocene age exposed about 275 feet above present sea level on the Ile d'Alma, Lake St. John County, is monazite bearing (Martens, 1929, p. 20). Adjacent areas are underlain by part of the Saguenay anorthosite, but granite, gneiss, and amphibolite are locally present in the distributive province from which the sand was derived, and muscovite-rich pegmatite dikes in the Saguenay area have long been known to be monazite bearing (M. J. Obalski, 1904, p. 173). The marine sand on the Ile d'Alma contains about 10 percent of heavy minerals, evenly distributed through it. A concentrate from the sand was described as having the following amount of monazite:

[Analyst: Martens, 1929 (p. 31)]

	Frequency percent		Frequency percent
Black opaque minerals	29	Zircon	3
Garnet	10	Rutile	.2
Hornblende	28	Biotite	Trace
Hypersthene	14	Monazite	.2
Augite	11	Altered feldspar	.5
Epidote	1		
Sphene	1	Total	99.9
Apatite	2		

Alluvial deposits around East Angus were prospected for black sand and gold in 1939 (Quebec Miner, 1939). Particular attention was said to have been given to possible economic occurrences of garnet, zircon, monazite, rutile, and ilmenite; but apparently very little if any monazite was recovered, because detrital monazite is not mentioned in the literature on this area.

SASKATCHEWAN

A northwest-trending fault zone between amphibolite and granite gneiss and pegmatite in the Lake Athabaska district near Uranium City was reported to contain 15 percent of monazite in a vein 12 feet wide (Mining World, 1955). Unconcentrated ore from the vein was reputed to average a little more than 1.0 percent of ThO_2.

Monazite occurs at a locality near the Fond-du-Lac River about 0.5 mile west of Stony Rapids and east of the east end of Lake Athabaska (Lang, 1952, p. 109). Its abundance and geologic relations are not known.

In the Beaverlodge area, migmatitic gneiss locally has thin biotite-rich layers which contain as much as 25 percent of monazite (Heinrich, 1958, p. 270).

Two concentrates from the Saskatchewan River were reported to contain extremely small amounts of monazite (Day and Richards, 1906b, p. 1220–1221). Both concentrates were black sand tailings from gold placers, but the exact localities were not described.

YUKON TERRITORY

Discovery of monazite in Yukon Territory was considered possible by Ellsworth in the early 1930's (1932a, p. 108), but the mineral was not found until the early 1950's. Monazite occurs in concentrates from Boulder Creek and Clear Creek, which are tributaries to the McQuesten River in the Mayo District (Lang, 1952, p. 40). Its source seems to be local granitic rocks, where it is associated with allanite.

GREENLAND

Medium- to fine-grained dark nepheline syenite (lujavrite) composing the youngest member of the Ilimaussaq massif in the Julianehaab District of southwestern Greenland contains accessory monazite, steenstrupine, and several unidentified radioactive minerals (Bondam and Sörensen, 1959, p. 555). Samples of the monazite have low alpha activity of 0–1,900 alpha particles per square centimeter per hour, which suggests that some, and possibly much, of the monazite from the nepheline syenite has little or no thorium. The rock is hydrothermally altered, and the monazite seems to have formed from eudialyte during the hydrothermal activity.

In the Kvanefjeld area, syenite and analcime-rich lujavrite contain many monazite-rich pseudomorphs after eudialyte (Bondam and Sörensen, 1959, p. 557). Black sands from the coast were said to contain very sparse monazite (Martens, 1929, p. 31).

Very small quantities of monazite occur in sand from the shore of a small lake on the island of Egedesminde south of Godhavn (Martens, 1929, p. 27, 31). The lake occupies part of the glaciated surface of the island and is in granite and granite gneiss. Heavy minerals make up 4 percent of the beach sand, and monazite is only 0.2 percent of the concentrate:

[Analyst: Martens, 1929 (p. 31)]

	Percent		Percent
Black opaque minerals	0.5	Apatite	4
Garnet	8	Zircon	2
Hornblende	63	Rutile	1
Hypersthene	4	Monazite	.2
Augite	3	Sillimanite	.2
Epidote	11		
Sphene	2	Total	98.9

HONDURAS AND BRITISH HONDURAS

A trace of monazite was reported by Day and Richards (1906b, p. 1222–1223) in a concentrate consisting dominantly of ilmenite, garnet, zircon, and magnetite from Trujillo in Honduras. The geologic source of the concentrate was not described.

Monazite occurs in granitic detritus and alluvium near the headwaters of Stamn Creek in British Honduras, where it is associated with detrital cassiterite and molybdenite (Thomson, 1952b, p. 319). The source of the detritus is a granite which intrudes sedimentary rocks of late Carboniferous age. At the contact the granite locally contains cassiterite.

MEXICO

Monazite is present as a minor accessory mineral in the La Grulla granodiorite in the Sierra San Pedro de Martir, Baja California (Jaffe and others, 1959,

p. 82). Alpha activity recorded for the monazite suggests that it may have about 4 percent of ThO_2.

The possible presence of monazite placers in the beach sands along the coasts of the State of Oaxaca was suggested by Gonzalez Reyna (1956, p. 323), but none had been reported as of 1960.

UNITED STATES OF AMERICA

Fluviatile monazite placers in the Piedmont province of North and South Carolina were a commercial source for monazite from 1887 to 1911 and 1915 through 1917 (table 30). During the later part of this same period a little monazite was also taken from valley placers in Idaho. In the late 1940's the placers in Idaho were reopened, and a monazite-bearing stream in the extreme western part of the Coastal Plain of South Carolina was dredged. Some ilmenite placers in Florida have a small byproduct output of monazite, as do lode mines for molybdenum in Colorado and spodumene in North Carolina. Large fossil placers of monazite have been found in the Western States and Michigan, but they have not been mined. The dependence of the United States on monazite as a source for the rare earths and thorium has been greatly lessened by the discovery of very large deposits of bastnaesite in California and thorite in the Rocky Mountains.

ALABAMA

The older reports on the mineral resources of Alabama did not discuss monazite, although at the time the reports were published, active mining of, or exploration for, monazite had been or was under way in North Carolina, South Carolina, and Florida (Smith and McCalley, 1904; Jones, W. B., 1926). Monazite was not reported from the mica pegmatites of Alabama (Heinrich and Olson, 1953, p. 408). In 1951, Mertie (1953) discovered monazite in Alabama, and by 1955, Pallister (1955, p. 33, 45, 47, 54) and Broadhurst (1955, p. 79) were referring to its occurrence in crystalline rocks and in streams in Chilton, Coosa, and Tallapoosa Counties and in crystalline rocks in east-central Alabama. Monazite is an uncommon mineral in these rocks and apparently is too sparse to be detected in most places by car-borne counters; thus, Stow (1955a, p. 18–19, 28) did not mention monazite in his description of the radioactive outcrops in Alabama, although he observed an area of anomalously high radioactivity to the southwest of Rockford that may relate to the monazite occurrences in Coosa County discovered in 1951 by Mertie (1953, p. 23).

The most thorough descriptions of monazite in Alabama were given by Mertie (1953, p. 15, 23, 26). He found that the Pinckneyville Granite is sparsely monazite bearing at 11 places in Coosa and Tallapoosa Counties, and he found small amounts of accessory monazite in granitic gneiss at 6 localities in Chambers County. These 17 mineralogical occurrences together form the southwest end of a belt of monazite-bearing crystalline rocks traced by Mertie (1953, pl. 1) 600 miles northeastward across the western part of the Piedmont province of Georgia, South Carolina, North Carolina, and Virginia. The southwest end of the belt is covered by the overlapping sediments of the Coastal Plain in Alabama. None of the occurrences in Alabama is a commercial source for monazite.

Streams in the area that is underlain by monazite-bearing granites and gneisses no doubt have small amounts of detrital monazite, as reported by Pallister (1955, p. 33), but no placers have been mined. Inasmuch as fluviatile placers having more favorable source areas in North Carolina were thought to be uneconomic sources for monazite (Overstreet, Theobald, and Whitlow, 1959, p. 714), it is not likely that economic stream placers exist in the less favorable source areas of the Piedmont province of Alabama.

Monazite occurs as accessory detrital grains in parts of the Coastal Plain sediments in Alabama and on the islands and beaches of the gulf coast west of the ilmenite placers near Panama City, Fla.

Sedimentary rock in the Tuscaloosa Formation of Cretaceous age at the inner edge of the Coastal Plain was found by Dryden (1958, pl. 22) to contain monazite at 17 out of 18 localities sampled from Phenix City to the Coosa River north of Prattville. The tenor of the monazite-bearing samples, as estimated by Dryden, was between 0.01 and 0.25 pound of monazite per cubic yard. Samples from other parts of the Coastal Plain in Alabama disclosed similar low abundances of monazite. At three localities from Troy to 20 miles north, the sedimentary rocks contained from 0.01 to 0.15 pound of monazite per cubic yard. A sample from Troy contained no monazite, and three samples from more than 20 miles south of Troy contained from 0.05 to 0.16 pound per cubic yard.

ALASKA

Monazite in Alaska was first described by Mertie (1925, p. 263) in a discussion of gold placers at Chandalar. It was again noted by Waters (1934, p. 239) in heavy minerals accompanying cassiterite in the Tofty area. As monazite is not an abundant mineral in Alaska, its distribution was not well known

TABLE 30.—*Monazite, in short tons, produced in North Carolina, South Carolina, Idaho, and Florida from 1880 to 1960*

Year	Source references	North Carolina	South Carolina	Idaho	Florida	United States total
1880	1	0.015				0.015
1881–6	2, 3	(1)				(1)
1887	4, 5	12				12
1888–92	5	(2)				(2)
1893		65				65
1894		273				273
1895		787				787
1896	2, 3, 6–8, 16	15				15
1897		22				22
1898		125				125
1899		175				175
1900	2, 3, 6–9, 16	454				454
1901	2, 3, 6–8, 16	374				374
1902	2, 3, 6–8, 16	401				401
1903	2, 6–8, 16	387	44			431
1904	2, 6–8, 16	343	29			372
1905	2, 7, 8, 10, 16	447	225			672
1906	2, 7, 8, 11–13, 16	349	74	2–3		423
1907	2, 7, 14, 16	228	46	(4)		274
1908	2, 14–16	155	56	(4)		211
1909	2, 14–16	196	75	(4)		271
1910	2, 3, 14–16	42	8	(4)		50
1911	15, 16	(4)				(4)
1912	15, 16	(4)				(4)
1913–14						
1915	3, 16	18				18
1916		19				19
1917	3, 13, 16	39			11	50
1918						
1919	3, 16					(5)
1920–24						
1925					1	1
1926–38	16					
1939–45	17					
1946–48	18, 19			[6] 40		40
1949	20			(7)	(8)	(9)
1950	21			(9)	(9)	(9)
1951	22–25			(9 10)	(9)	(9)
1952	26			(9)	(9)	(9)
1953	27, 28	(11)		(9 12)	(9)	(9)
1954	29		(13)	(9 14)	(9)	(9)
1955	24, 30		(15)	(9 16)	(17)	(9)
1956	31		(15)	(18)	(17)	(7)
1957	32		(15)	(18)	(15)	(7)
1958	33		(19)	(20)	(8)	(7)
1959	34, 35			(21)	(22)	[23] 1,143
1960	36				(8)	(7)

1 A few tons mined in 1886 but none shipped.
2 A few tons produced per year, but record not kept.
3 Not marketed.
4 Small production, not marketed.
5 One producer, figures not released, point of origin not specified in references.
6 Recovered from Boise Basin area, Boise County.
7 Output not reported.
8 Very small production as a byproduct of ilmenite mining.
9 Production classified.
10 Production commenced at Big Creek, Valley County, Idaho; three dredges in operation by end of year.
11 One producer, output not released, probably small.
12 Three dredges in operation at Big Creek.
13 Dredge under construction on Horse Creek, Aiken County, S.C.
14 Two dredges in operation at Big Creek; construction commenced on dredge at Bear Valley.
15 One producer, output not released.
16 Output at Big Creek ceased in August 1955; preparations to mine continuing at Bear Valley.
17 Two producers, output not given.
18 Monazite recovered beginning in June 1956 as a byproduct of mining euxenite placer in Bear Valley, production figures not released.
19 Greatly reduced production, figures not released.
20 Greatly reduced production at Bear Valley, a little monazite shipped from Boise Basin, figures not released.
21 Byproduct monazite from stockpile built in 1958 dredging at euxenite placer in Bear Valley and from ilmenite stockpile in Boise Basin.
22 Three producers, output not given.
23 Combined monazite, bastnaesite, thorite, and thorium-rare earths residue.

Sources:
1. Genth and Kerr (1881, p. 84).
2. Pratt (1916, p. 52–53).
3. Santmyers (1930, p. 15).
4. Pratt (1903, p. 183).
5. Pratt (1902, p. 61).
6. Pratt (1905, p. 45–46).
7. Pratt (1908, p. 66).
8. Pratt (1907b, p. 123).
9. Pratt (1901, p. 30).
10. Pratt (1907a, p. 41).
11. Franklin Inst. Jour. (1908, p. 318).
12. Fleck (1909, p. 205).
13. Sloan (1908, p. 14).
14. Pratt and Berry (1919, p. 104–105).
15. Pratt (1914, p. 81).
16. Houk (1946, p. 11–12).
17. Matthews (1948, p. 1208).
18. Clark (1950, p. 1322).
19. Kline, Carlson, and Griffith (1950, p. 24).
20. Clark (1951, p. 1249).
21. Lamb, North, and Chandler (1953, p. 1354–1355).
22. Keiser (1954, p. 1302).
23. Lamb (1955a, p. 4).
24. Eilersten and Lamb (1956, p. 25).
25. Kline and Carlson (1954, p. 13).
26. Keiser (1955, p. 1089).
27. Councill (1955, p. 6).
28. Crawford (1956, p. 1212).
29. Crawford (1958a, p. 1157–1158).
30. Crawford (1958b, p. 1125).
31. Crawford (1958c, p. 1156–1157).
32. Paone (1958, p. 1146–1147).
33. Paone (1959, p. 1037–1038).
34. Lewis (1960, p. 895).
35. Paone (1960, p. 1070).
36. Parker (1961, p. 927).

until the late 1940's and early 1950's when the U.S. Geological Survey searched for occurrences of radioactive minerals. Between 1945 and 1952 the Survey staff examined several thousand heavy-mineral concentrates from mining districts throughout the State and conducted ground and airborne radiometric reconnaissance at many selected localities. Less than 48 occurrences of monazite were discovered, and even in these occurrences monazite is generally exceedingly scarce.

Two reasons seem to account for the sparseness of the known monazite-bearing areas in Alaska. One is the possible failure of radiometric surveys to detect monazite in areas masked by heavy vegetation. Undoubtedly monazite has been missed by both ground and airborne radiometric surveys, but at most localities where it has been found in Alaska, monazite is present in such small amounts that the discovery itself indicates a high sensitivity of the radiometric methods. The second, and main, reason for the sparseness of monazite seems to be a geologic environment that is generally unfavorable for its development.

Monazite in Alaska is ordinarily found as detrital grains in stream sediments, but at several localities detrital monazite occurs in littoral sediments. The detrital monazite was derived from granitic rocks in which it is a minor accessory mineral. The monazite-bearing granitic rocks are massive and are emplaced in almost unmetamorphosed to moderately metamorphosed sedimentary rocks; such rocks are not usually rich in monazite. The chief host rocks of monazite, which, elsewhere in the world, are profoundly plutonic rocks, such as sillimanite gneisses, granulites, and migmatites, have not been discovered in Alaska. Absence of these rock types accounts for the sparseness of detrital monazite.

Monazite-bearing carbonate-hematite veins have been found in southeastern Alaska. The monazite-bearing veins are radioactive, but the amount of thorium in the monazite is not known. In many respects these veins resemble those associated with carbonatite deposits elsewhere in the world, and carbonatites contain thorium-poor monazite.

The monazite-bearing localities are distributed as follows: 4 in southeastern Alaska, 7 in south-central Alaska, 13 in east-central Alaska, 5 in northeastern Alaska, 6 in central Alaska, 3 in southwestern Alaska, and 4 in west-central Alaska.

SOUTHEASTERN ALASKA

A minor amount of a mineral that was doubtfully identified as monazite was found by West and Benson (1955, p. 37) in a pyrrhotite-rich concentrate from a molybdenite-gold-quartz vein and its granitic wallrock exposed in the underground workings of the Mountain View gold mine in the Hyder district. In addition to pyrrhotite and monazite, the concentrate contained large amounts of rutile, molybdenite, and pyrite, and small amounts of chlorite, prehnite, apatite, amphibole, carbonate minerals, and an unidentified brownish-black isotropic mineral. The vein fills a fissure in a granitic dike that cuts across sedimentary and volcanic rocks of the Hazelton Group of Jurassic(?) age and also cuts the intrusive Texas Creek Granodiorite of Cretaceous or Jurassic age. The monazite may have come from either the vein or the dike. Neither the greenstone, tuff, volcanic breccia, graywacke, slate, argillite, and sparse limestone of the Hazelton Group nor the Texas Creek Granodiorite are known to have monazite.

Many narrow mesothermal carbonate-hematite fissure veins are exposed along the shore at Salmon Bay on the northeast coast of Prince of Wales Island. Houston and associates (Houston and others, 1958, p. 6–22; Houston and others, 1953; White and others, 1952, p. 16) reported that the veins, which are locally monazite bearing, cut well-indurated graywacke of Silurian age which overlies limestone. The sedimentary rocks at Salmon Bay are intruded by many lamprophyre dikes, some olivine basalt dikes, and a few phonolite dikes; coarse-grained igneous rocks are absent.

Three varieties of veins are described, but only the most common one is radioactive and contains monazite. This type of vein ranges in width from a fraction of an inch to several feet, and averages 2.5 inches. These three varieties of veins fill fissures in graywacke and are composed mainly of a grayish-white carbonate mineral of the dolomite-ankerite series (Houston and others, 1958, p. 10–11). Alkalic feldspar, red hematite, specularite, and pyrite are common, and locally siderite and magnetite are abundant. Small amounts of quartz, chalcedony, chlorite, calcite, parisite, bastnaesite, muscovite, fluorite, apatite, thorite, zircon, monazite, epidote, topaz, garnet, chalcopyrite, and marcasite are present. Monazite is very scarce and occurs in only a few veins.

Traces of monazite occur in three (table 31) out of six heavy-mineral concentrates from alluvium in the Goddard Hot Springs area of Baranof Island (West and Benson, 1955, p. 47–49). The monazite-bearing concentrates come from streams that drain areas underlain by granite, altered sandstone, conglomerate, graywacke, and slate. The granite is intruded by narrow dikes of spessartite lamprophyre.

Near Juneau some weakly radioactive sand was dredged during construction at the airport in 1953 (Holdsworth, 1955, p. 56). Possibly some of the radioactivity was emitted by monazite.

TABLE 31.—*Mineralogical composition, in percent, of monazite-bearing concentrates from streams in the Goddard Hot Springs area, Baranof Island, Alaska*

[Modified from West and Benson (1955, p. 49)]

	3305	3302	3312
Allanite	6	Trace	7
Apatite	Trace	0	0
Augite	3	Trace	3
Biotite	0	0	1
Chlorite	Trace	0	1
Clinozoisite	1	0	Trace
Diopside	2	12	1
Epidote	Trace	Trace	2
Garnet	14	23	15
Hornblende	6	5	10
Hypersthene	Trace	Trace	5
Ilmenite	55	55	44
Limonite	0	Trace	Trace
Magnetite	Trace	Trace	3
Marcasite	2	0	0
Monazite	Trace	Trace	Trace
Pyrite	0	0	1
Rutile	Trace	Trace	0
Scheelite	Trace	0	Trace
Sphene	2	0	1
Zircon	7	3	5
Total	98	98	99

3305. Stream formed by the hot springs.
3302. Stream 1 mile northeast of Goddard.
3312. Stream draining lake north of the hot springs.

SOUTH-CENTRAL ALASKA

The seven monazite occurrences in south-central Alaska are associated with gold placers. Six of these occurrences were briefly noted by Bates and Wedow (1953, p. 8–9), and the seventh, monazite in the Cache Creek–upper Peters Creek area of the Yentna district, was discussed by Robinson, Wedow, and Lyons (1955, p. 5–7, 20–21). According to Bates and Wedow, monazite was observed in prospectors' samples from the Mount Spurr area, in concentrates from gold placers at Roundbend Bar, Red Hill Bar, and Shalon Bar on the Kahiltna River and from gold placers in the Petersville area and in Poorman Creek.

The Cache Creek–upper Peters Creek area of the Yentna district is underlain by tightly folded, weakly metamorphosed slate and graywacke interbedded with some quartzite and conglomerate (Robinson and others, 1955, p. 5–7); these rocks are unconformably overlain by pebble gravel that is slightly deformed, gravel that is cemented, arkose, clay, and lignite; these units are wholly or in part of Eocene age. Glacial-outwash gravel, possibly late Tertiary in age, overlies the Eocene sediments, and is mantled by glaciofluvial gravel of Quaternary age. The present streams have cut through the Quaternary gravel and have formed as many as seven bench levels below the top of the Quaternary glacial deposits. Stream gravel commonly veneers the benches, the youngest gravel being in the flood plains and channels of the present streams.

Concentrates from the different gravel deposits contain about the same kinds of heavy minerals, but in variable proportions. Sand and gravel of Eocene age yield concentrates low in sulfide minerals and lacking in tourmaline and apatite. Concentrates from the late Tertiary gravel are rich in pyrite, and those from the gravel of Quaternary age are rich in andalusite and cassiterite. Compared with the other gravels, concentrates from the present flood-plain gravels contain more apatite, tourmaline, monazite, allanite(?), and iddingsite(?). Common minerals in all the concentrates are zircon, hornblende, hypersthene, augite, epidote, garnet, pyrite, ilmenite, chromite, cassiterite, and magnetite. Scarce or variably present minerals and native elements include gold, tourmaline, andalusite, biotite, chlorite, iron oxide minerals, allanite(?), arsenopyrite, copper, stibnite(?), apatite, sphene, iddingsite, prehnite, rutile(?), marcasite, galena, platinum, and monazite.

The origin of the monazite in the sediments is not discussed. Monazite is too sparse in the concentrates for the area to be of economic importance.

EAST-CENTRAL ALASKA

In east-central Alaska, 5 of the 13 occurrences of monazite were merely mentioned by Bates and Wedow (1953, p. 9–10). These are monazite associated with gold in stream placers at Atwater Bar on the Mosquito Fork of the South Fork of the Fortymile River, Copper Creek, Coal Creek, and Woodchopper Creek and monazite in granitic bedrock and fluvial gold placers in the Slate Creek area.

Ober Creek near Donnelly contains placer gold together with small quantities of detrital monazite, tourmaline, zircon, fluorite, and epidote (Wedow and others, 1954, p. 18). The drainage basin of Ober Creek is underlain by schists and gneisses of Precambrian(?) age, but the source of the monazite is not known.

Placer concentrates from a gold dredge on Nome Creek in the Chatanika area contain sparse monazite and tourmaline and abundant cassiterite. The source of the monazite is unknown (Wedow and others, 1954, p. 8–9), but it may come from a granite stock at the head of Nome Creek. The stock is of Mesozoic(?) age and intrudes quartz-mica schist, quartzite, and some augen gneiss and crystalline limestone of the Birch Creek Schist.

Placer concentrates from the Livengood area, particularly from Ruth Creek, contain a few grains of monazite (Bates and Wedow, 1953, p. 10; Wedow and others, 1954, p. 11).

Granitic rock of possible Mesozoic(?) age intruded into schist and exposed on Excelsior Creek in the Eagle-Nation area contains a few grains of monazite (Wedow, 1954, p. 6–9). Of 38 concentrates from the granite, only 1 contained monazite. Sediments of Tertiary age composed of granitic detritus and probably resting directly on granitic bedrock are exposed along Mission Creek and American Creek in the Eagle-Nation area. Suites of heavy minerals from these sediments contain ilmenite, iron oxide minerals, zircon, small amounts of garnet and anatase, and traces of epidote, hornblende, hypersthene, rutile, biotite, apatite, and monazite. No economic monazite placers are known in the area.

Out of 13 heavy-mineral concentrates from the Miller House–Circle Hot Springs area (Nelson and others, 1954, p. 11–15), 3 contain monazite (table 32).

TABLE 32.—*Mineralogical composition, in percent, of monazite-bearing concentrates from the Miller House–Circle Hot Springs area, Alaska*

[Compiled from Nelson and others (1954, table 8). Symbol used: --, absent]

	4718	4677	4679
Allanite	--	--	Trace
Apatite	--	Trace	--
Arsenopyrite	--	Trace	1
Biotite	24	10	Trace
Bismuthinite	--	--	Trace
Cassiterite	--	--	3
Chalcopyrite	--	Trace	--
Chlorite	--	7	Trace
Diopside	--	--	3
Fluorite	--	1	--
Garnet	1	1	10
Gold	--	--	Trace
Hematite	--	2	5
Ilmenite	10	60	50
Jamesonite	--	Trace	--
Limonite	--	Trace	--
Magnetite	--	--	15
Malachite	Trace	--	--
Monazite	10	4	Trace
Muscovite	--	--	Trace
Pyrite	--	1	1
Pyrochlore-microlite	--	--	Trace
Pyrrhotite	35	--	--
Scheelite	Trace	Trace	1
Sphalerite	--	1	--
Sphene	--	--	1
Spinel	--	--	1
Topaz	5	--	Trace
Tourmaline	--	--	1
Uranothorianite	--	--	Trace
Wolframite	--	--	5
Zircon	15	10	1
Total	100	97	98

4718. Granite exposed in Bedrock Creek near Miller House.
4677. Granite bedrock underlying H. C. Carsten's gold placer on Portage Creek near Circle Hot Springs.
4679. Sluice-box concentrate from gold placer in same locality as 4677.

One concentrate is from granite of Mesozoic(?) age; the second concentrate, from granite bedrock underlying a gold placer; and the third is from the placer. The two concentrates from granite are unusually rich in monazite for rock in Alaska.

NORTHEASTERN ALASKA

Ten placer concentrates were collected from the Wiseman gold area by White (1952, p. 8–11), but only 1, a sample from Rye Creek, contains monazite. Even for that sample the following composition shows that monazite is less than 1 percent of the concentrate:

	Percent		Percent
Ilmenite	35	Gold	Trace
Schist fragments	25	Scheelite	Trace
Chlorite	20	Sphene	Trace
Andalusite	7	Kyanite	Trace
Zoisite	5	Zircon	Trace
Epidote	5	Monazite	Trace
Pyrite	3		
Chalcopyrite	Trace	Total	100
Galena	Trace		

Monazite found in the Chandalar gold district in concentrates from placers from Big Creek was the first reported occurrence in Alaska. In the same district, concentrates from placers yield trace amounts of monazite at Tobin Creek, a few grains at Little Squaw Creek, a few grains together with zircon and uranothorianite at the middle fork of Big Squaw Creek, and some from Gold Bench on the South Fork of the Koyukuk River (Mertie, 1925, p. 263; White, 1952, p. 8–12; Nelson, 1953; Nelson and others, 1954, p. 16–19). Concentrates from Gold Bench, a deposit of high-level stream gravel 200–300 feet above the river, consist of magnetite, garnet, hematite, zircon, olivine, epidote, sphene, pyrite, scheelite, galena, chalcopyrite, rutile, cinnabar, cassiterite, bismuthinite(?), thorianite(?), and monazite. Monazite occurs only in trace amounts in the concentrates. The Chandalar area is underlain by mica and chlorite schists cut by dikes of greenstone and granite gneiss. Although Mertie (1925, p. 263) suggested that the geologic source of the monazite might be some highly silicic granitic rock, possibly pegmatite, later investigations have not verified this. The survey by Nelson, West, and Matzko (1954, p. 16) did show, however, that finding commercial quantities of monazite in stream gravel in the Chandalar district is unlikely.

CENTRAL ALASKA

Quartz monazite at Elephant Mountain contains monazite, and the nearby stream deposits at Eureka are monazite bearing (Moxham, 1954a, p. 6). The quartz monzonite intrudes slate, quartzite, and schist.

The Tofty tin deposits in the Manley Hot Springs–Rampart district were first observed to contain monazite by Waters (1934, p. 239–242). These tin deposits consist of a belt of placers in gravel of late Tertiary or early Quaternary age buried under 15–80 feet of frozen silt of Pleistocene age. Cassiterite and gold are mined, and some chromite is found at the west end of the belt. Several possible sources for the placer cassiterite have been suggested (Waters, 1934, p. 242–246; Moxham, 1954a, p. 6), but tin lodes have not been found.

The monazite described by Waters occurred in part as fine-grained pebble-forming aggregates. He mentioned (Waters, 1934, p. 239) a very well rounded fine-grained light-buff pebble of monazite measuring 0.75 inch in its greatest dimension from the north side of Deep Creek and well-rounded light-buff very fine grained pebbles of monazite measuring 1 inch in their greatest dimension from Sullivan Creek just north of the old site of Tofty. At Deep Creek the placer monazite is accompanied by cassiterite, pyrite, ilmenite, picotite, magnetite, zircon, quartz, and eschynite. The monazite from Sullivan Creek is accompanied by the same minerals plus xenotime, orthoclase, plagioclase, gold, copper, apatite, epidote, brookite, and anatase.

Monazite was absent from all five samples taken by Waters from streams north of the Tofty tin belt. Out of 14 samples from these streams, 9 contain monazite. One out of two samples from streams south of the belt is monazite bearing. Thus, the dominant monazite-bearing stream deposits are within the tin belt. Monazite from the Tofty tin placers is weakly radioactive. Moxham (1954a, p. 5) reported that the equivalent uranium content of the monazite does not exceed 1 percent. This low content suggests that the abundance of ThO_2 in the monazite does not exceed 4 percent. Low abundances of thorium oxide are characteristic of monazite from many tin deposits.

Monazite-bearing granite of Tertiary age forms a stock in slate, quartzite, and schist of Cretaceous age between Hot Springs Dome and Manley Hot Springs. Most of the streambeds in the area underlain by the granite contain monazite, but those in the metasedimentary rocks seemingly lack monazite. Indirect evidence from radiometric traverses indicates that monazite is uncommon, possibly virtually absent, in the aureole of metasedimentary rocks around the stock (Moxham, 1954a, p. 4).

Monazite is found in gold placers in gravel of Tertiary age exposed on Boulder Creek in the Manley Hot Springs–Rampart district. The monazite may have come from a stock of quartz monzonite which crops out nearby at Roughtop Mountain (Moxham, 1954a, p. 6).

SOUTHWESTERN ALASKA

The Nixon Fork gold district is underlain by limestone of Paleozoic age, and sandstone, shale, and slate of Late Cretaceous age (White and Stevens, 1953, p. 10–12). This sedimentary sequence is cut by quartz monzonite thought to be Eocene in age. Contact-metamorphic zones between the limestone and the quartz monzonite are rich in garnet and are the site of lodes containing oxidized copper-gold ore and bismuth minerals. Also present in the contact zone are a variety of radioactive minerals including sphene, allanite, vesuvianite, zircon, uraniferous thorianite, and parisite (a rare-earth fluocarbonate). More than 100 heavy-mineral concentrates were prepared by White and Stevens (1953, p. 16) from stream deposits and rock units in the district, but only 1 concentrate, which was from a gold placer, contained monazite. The radioactivity of the monazite was not discussed.

Julian Creek, an east-flowing tributary to the upper Middle Fork of the George River 25 miles southeast of Flat, drains an area underlain by sandstone and slate cut by a few narrow dikes of porphyritic granite, all of which are presumed to be Late Cretaceous in age (White and Killeen, 1953, p. 16–18). A concentrate from a sluice box at the Harry Steen gold mine on Julian Creek contained 10 percent of rock-forming minerals, 80 percent of pyrite, and 5 percent each of garnet and monazite. The monazite is thorium bearing, but the amount of thorium is not known.

Questionably identified monazite occurs in minor amounts in two out of three concentrates from sluice boxes at a gold placer on Candle Creek (White and Killeen, 1953, p. 16–18). Candle Creek enters the Tatalina River 5 miles southwest of McGrath. Gold has been dredged from placers 4 miles downstream from the head of the creek just below a contact between a small quartz monzonite, exposed in the upper reaches of the stream, and sandstone and shale of Cretaceous age in the lower course of the stream. Some of the placer gold apparently comes from quartz veins associated with the quartz monzonite. The two monazite-bearing concentrates consist of about 5 percent of rock-forming minerals, 90 percent of spinel, 3 percent of zircon, and 2 percent of a mixture of cinnabar, scheelite, and monazite(?). The source of the monazite was not specified.

WEST-CENTRAL ALASKA

Monazite was found by West (1953, p. 2, 4, 7) in one concentrate from the east shore of Golovnin Bay between Cape Darby and Portage Creek on the Seward Peninsula. Beach sand in the area is derived from an igneous complex of pre-Cretaceous age which makes up the Darby Mountains. The complex is composed mainly of gneissic granite which has been metamorphosed to various degrees. Some diorite and greenstone are included in the complex. Even-grained to porphyritic granite, also said to be pre-Cretaceous in age, intrudes the complex. Which members of the complex contribute the monazite to the beach sand are not known.

A monazite-bearing stock of granite forms the central part of Ear Mountain on the Seward Peninsula. Killeen and Ordway (1955, p. 65–68) stated that the stock is 2 miles in diameter and that it intrudes shale, slate, quartzite, and limestone. They thought the limestone to be of Ordovician age, but the ages of the other rocks are uncertain. Altered gabbro intrudes the sedimentary rocks, and several dark-gray mafic dikes containing large phenocrysts of biotite cut the granite stock. The stock has apophyses of alaskite, and a variety of veins cut rock in the area. Lime-silicate rocks at the contact between the granite and limestone consist of garnet, hedenbergite, vesuvianite, scapolite, axinite, and tourmaline and minor amounts of hornblende, datolite, magnetite, and pyrite.

Monazite is such a common accessory mineral in the granite stock that it can be seen in thin section (Killeen and Ordway, 1955, p. 86). Minerals having high thorium to uranium ratios, such as monazite, occur as accessories in the granite, but they were not observed in the veins. Minerals having high uranium to thorium ratios were found in the veins. This distribution suggested to Killeen and Ordway that the thorium was largely concentrated in the early formed accessory minerals of the granite and that the uranium was concentrated in the final products of crystallization.

Concentrates were collected by Killeen and Ordway (1955, p. 76–83) from 100 localities in streams rising in the area underlain by the granite and flowing out onto the area underlain by sedimentary rocks. The total volume of monazite in concentrates from individual riffles was very small, but monazite was found in every concentrate. Killeen and Ordway estimated that the riffle gravels contained from 0.7 to 32 pounds of concentrate per cubic yard, the heaviest concentrates being obtained downstream from the contact between the granite and limestone. Monazite, cassiterite, and zircon constituted most of the concentrate from streams in the area underlain by the granite. Downstream from the granite these minerals are accompanied by variable, locally large, amounts of garnet, vesuvianite, axinite, diopside, hypersthene, biotite, tremolite, apatite, scheelite, fluorite, topaz, magnetite, olivine, epidote, danburite, scapolite, limonite, hematite, and stokesite. The placers at Ear Mountain are not a commercial source for monazite (Killeen and Ordway, 1955, p. 91).

Brooks Mountain on Seward Peninsula is composed of granite of Mesozoic(?) age intruded into black slate of Precambrian or Cambrian age and into the Port Clarence Limestone of Ordovician, Silurian, and Devonian age (White and others, 1952, p. 2–6; West and White, 1952, p. 2). The granite is porphyritic and coarse grained and has a medium-grained equigranular border phase. It consists of orthoclase, plagioclase, biotite, smoky quartz, and black tourmaline, and accessory monazite, zircon, xenotime, anatase, magnetite, and ilmenite. The radioactivity of the granite was said to be emitted by zircon, monazite, and xenotime, but it is low (West and White, 1952, p. 3–7). The composition of the monazite is not known.

Cape Mountain on Seward Peninsula is a nearly circular stock of granite intruded into limestone. Cassiterite lodes and placers have been found in both the granite and the limestone along the northeast margin of the stock. Some distant placers indicate that cassiterite lodes are also in the limestone away from the contact. Monazite, xenotime, and zircon are in placer concentrates from parts of the area near Cape Mountain; thus, the source of the monazite is probably the granite or the lodes (Bates and Wedow, 1953, p. 6).

The composition of concentrates from drill holes in the area was described by Mulligan and Thorne (1959, p. 38, 48, 62, 66). They showed that radioactive minerals are absent from cassiterite-bearing concentrates from 209 churn-drill holes and 10 test shafts on Cape Creek and are present in 71 out of 83 samples from holes on Boulder Creek. The composition of monazite-bearing concentrates from Boulder Creek is given in table 33.

The valley of Cape Creek is underlain by limestone and some layers of schist (Steidtmann and Cathcart, 1922, p. 97), and the valley of Boulder Creek heads in granite on the northeast flank of Cape Mountain and flows northward across the contact between the granite and limestone (Steidtmann and Cathcart, 1922, p. 97; Mulligan and Thorne, 1959, p. 48–49). The mineralogical evidence from the churn-drill holes shows that the monazite comes from the granite stock at Cape Mountain.

ARIZONA

Monazite was first recognized in Arizona in 1905 by Day (1905a, p. 9), who identified it in black sand from a placer in Yavapai County. Further descriptions by Day and Richards (1906b, p. 1180–1181) identified the

TABLE 33.—*Mineralogical composition, in percent, of monazite-bearing cassiterite concentrates from churn-drill line 94 in Boulder Creek valley in area underlain by limestone about 0.25 mile downstream from granite, Seward Peninsula, Alaska*

[Mulligan and Thorne (1959, p. 48). Symbol used: --, absent]

	Churn-drill hole						
	24	26	28	32	34	36	38
Cassiterite	40	35	40	50	45	70	20
Calcite	35	35	--	5	10	--	--
Dolomite			--	--		2	1
Quartz	20	25	40	25	25	[1] 20	45
Augite	3	--	--	--	--	--	--
Diopside	--	2	10	[2] 12	[3] 5	--	[4] 15
Clay	--	--		3	5	4	5
Shale	--	--	10	--	--	--	--
Feldspar	--	1		[5] 5	8	--	10
Epidote	--	1	--	--	--	Tr.	--
Biotite	1	1	Tr.	--	1	1	[6] 2
Garnet			Tr.	--	Tr.	1	1
Tourmaline	1	--	Tr.	Tr.	--	1	1
Chlorite	--	--	Tr.	--	--	--	--
Hornblende	--	--	--	--	1	--	Tr.
Hematite	--	--	--	--	--	1	--
Staurolite	--	--	--	--	--	Tr.	--
Scheelite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Zircon	--	Tr.	--	--	Tr.	--	--
Monazite	Tr.	Tr.	--	Tr.	Tr.	Tr.	Tr.
Xenotime	--	--	--	Tr.	Tr.	Tr.	Tr.
Apatite	--	--	--	--	--	--	Tr.

[1] Includes feldspar.
[2] Includes garnet and epidote.
[3] Includes epidote.
[4] Includes augite and epidote.
[5] Includes biotite.
[6] Includes chlorite.

locality as Black Canyon Creek and showed that the concentrate consisted mainly of magnetite and hematite, with some garnet and gold but only a trace of monazite.

Detrital monazite was discovered by A. E. Knowland in stream gravel in the Chemehuevis mining district about 20 miles southeast of Topock in Mohave County (Heineman, 1930, p. 536; Wilson, E. D., 1939, p. 49; Galbraith, 1947, p. 55; Anthony, 1948, p. 15; Moore, R. T., 1953, p. 26). It is sparingly scattered through the gravel in an area of about 2 square miles. The grains of monazite range from small particles to pebbles 0.5 inch across, and they are euhedral to subrounded. Even the most rounded grains retain vestigial crystal faces. Yellow-brown, red-brown, and dark-brown monazite is most common. The specific gravity of the monazite is 5.04. Analyses have not been reported, and the source, which presumably is nearby, has not been found.

A long, narrow vein in a granite dike in the Aquarius Mountains, Mohave County, contains quartz, chevkinite, sphene, monazite, apatite, and cronstedtite (Kauffman and Jaffe, 1946, p. 582, 587). Cracks in anhedral chevkinite are healed with aggregates of euhedral apatite and sphene, small subhedral to large euhedral grains of monazite, large uniformly oriented flakes of cronstedtite, and a small amount of strained quartz. Granite augen gneiss in Mohave County contains accessory monazite (see section on "Clark County, Nevada").

At several localities in northern Arizona, radioactive fossil placers were said to be present in sandstone of Late Cretaceous age, but the exact sites were not specified (Chenoweth, 1957, p. 217). Similar deposits are very common in the San Juan Basin of Colorado and New Mexico.

ARKANSAS

Fine-grained earthy monazite occurs in an apatite-pyrite vein in carbonatite on East Tufa Hill at Magnet Cove, Hot Spring County (Rose and others, 1958, p. 995; Fryklund and Holbrook, 1950, p. 38–39). Monazite was interpreted by Rose and associates to have formed by the weathering of the apatite and is not considered to be an original mineral in the vein. The evidence for this interpretation is not compelling, but the material with which Rose and associates worked was thoroughly weathered. The monazite resembles monazite from other carbonatite bodies and low-temperature veins in carbonate rocks in that it is devoid of thorium.

Ilmenite-bearing layers of crossbedded, friable sand and clay near the top of the Tokio Formation of Late Cretaceous age contain sparse monazite in the vicinity of Mineral Springs, Howard County, Arkansas (Holbrook, 1948, p. 5–9; DeMent and Dake, 1948, p. 11). The area of exposed fossil placers covers at least 6 square miles on the northwest side of the town of Mineral Springs. In their richest parts the placers were said to contain from 1.4 to 12.8 percent of TiO_2, but the amount of monazite was reported to be too small to mine alone. A possible byproduct of monazite output might be obtained if the deposits were worked for ilmenite.

The Williana gravel, a pre-Wisconsin deposit of Quaternary age in the lower Mississippi Valley, is locally monazite bearing. A concentrate made from Williana gravel exposed just north of Jonesboro, Craighead County, Ark., contained a little, possibly as much as several percent, of monazite (Fisk, 1951, p. 342):

	Percent		*Percent*
Epidote	2	Tourmaline	16
Amphibole	2	Other minerals (fluorite, monazite, corundum, undetermined minerals)	7
Zircon	36		
Sphene	5		
Rutile	13		
Staurolite	14		
Andalusite	2	Total	100
Kyanite	3		

Monazite is present in but rarely makes up more than 1 percent of the heavy-mineral suite from the present sand of the Mississippi River (Russell, 1937, p. 1330). In a study of 144 samples of heavy minerals taken from sand in the Mississippi River at localities between Cairo, Illinois, and Profit Island, Louisiana, including samples from Blytheville, Mississippi County, Arkansas, and Helena, Phillips County, Arkansas, Russell (1937, p. 1316–1347) observed that no decrease in the relative abundance of monazite took place downstream, although such decrease might be expected owing to the brittleness and softness of monazite. Instead of a decrease, the relative abundance of monazite, and also of zircon, sphene, and rutile, increased slightly downstream. This apparent increase in abundance was attributed to the small sizes of these minerals and to a progressive sorting on the basis of size, the small-sized grains becoming more abundant in concentrates from sand in the downstream reaches of the river. Russell also observed in this important study that the persistent detrital minerals are those most resistant to chemical destruction; their relative resistance to mechanical disintegration was of little consequence in their survival during transport (Russell, 1937, p. 1347).

Monazite was present in 3 out of 4 concentrates from Mississippi River sand taken in the vicinity of Blytheville, and it was present in 10 out of 10 concentrates from the Helena area, Arkansas. In no sample did it attain an abundance as great as 1 percent of the concentrate.

CALIFORNIA

Monazite has been observed in the black sands of stream and beach placers in California since the early 1900's and, since the 1930's, has been found in a few crystalline rocks in the State, but no commercial deposits of monazite are known (Day, 1905a, p. 9; California Div. Mines Staff, 1945, p. 520; Oakeshott, 1950, p. 136). One of the world's largest known concentrations of the rare earths, however, is found in the bastnaesite deposits in the Mountain Pass district, San Bernardino County, Calif. (Olson and others, 1954, p. 33–38; Eng. and Mining Jour., 1952a; Murdoch and Webb, 1956, p. 223; Walker and others, 1956, p. 5, 7; Jarrard, 1957, p. 43; Jaffe, 1955, p. 1247–1249).

CRYSTALLINE ROCKS

The geology of the bastnaesite deposits at Mountain Pass, San Bernardino County, has been described in detail by Olson, Shawe, Pray, and Sharp (1954, p. 4–62), and the relations and composition of the monazite in them have been summarized by Jaffe (1955, p. 1247–1255). According to these writers the Mountain Pass district is in an area of Precambrian garnetiferous mica gneiss and schist, biotite-garnet-sillimanite gneiss, amphibolite, granitic gneiss, and pegmatite. Intrusive into these rocks, and apparently also of Precambrian age, is a suite of potassium-rich igneous rocks consisting of shonkinite, syenite, and granite; these rocks form small stocks and thin dikes. In and near the southwest side of a large composite stock of shonkinite and syenite are veins and an elongate mass of rare-earth-bearing carbonate rock. Almost 60 percent of the carbonate rock is composed of mixtures of calcite, dolomite, ankerite, and siderite. The remainder of the rock is barite, bastnaesite, parisite, quartz, and variable but minor amounts of crocidolite, biotite, phlogopite, chlorite, muscovite, apatite, hematite, goethite, fluorite, monazite, galena, allanite, cerite, sphene, pyrite, chalcopyrite, tetrahedrite, malachite, azurite, strontianite, cerussite, wulfenite, aragonite, and thorite. The carbonate bodies are interpreted by Olson and associates as probably originating as the end product of the magmatic differentiation of the alkaline magma from which the shonkinite, syenite, and granite were formed.

The monazite occurs mainly in dolomitic masses of carbonate rock, and thorite occurs principally in the veins. The monazite is in small subhedral to euhedral grains that are brown, reddish brown, or yellowish brown. They have from 1 to 3 percent of ThO_2 (Olson and others, 1954, p. 38).

Analysis of monazite, having a specific gravity of 4.98, from medium- to coarse-grained barite-carbonate rock composed of calcite, barite, bastnaesite, parisite, phlogopite, monazite, galena, pyrite, quartz, and hematite showed the following percentage of thorium oxide:

[Analysts: A. M. Sherwood and H. J. Rose, Jr. (in Jaffe, 1955, p. 1250)]

	Percent		*Percent*
Ce_2O_3	36.19	U_3O_8	[1] 0.002
La_2O_3	19.65	P_2O_5	29.23
Nd_2O_3	8.20	SiO_2	.70
Pr_2O_3	2.94		
Sm_2O_3	.85	Total	100.77
ThO_2	3.01		

[1] U=0.002 percent determined flourimetrically by Frank Cuttitta.

Another sample of monazite from the same carbonate mass was estimated to contain 1.54 percent of ThO_2 on the assumption that all the alpha activity of the mineral was from thorium (Jaffe, 1955, p. 1254). A specimen of monazite from fine- to medium-grained carbonate rock containing dolomite as the dominant carbonate mineral was analysed by A. M. Sherwood and Frank Cuttitta, U.S. Geological Survey, and found to contain 2.92 percent of ThO_2 and 0.002 percent of U_3O_8 (Jaffe, 1955, p. 1253).

The composition of a precipitate of the total rare earths and thorium oxide from a specimen of monazite from the Mountain Pass bastnaesite deposits has been reported by Murata, Rose, and Carron (1953, p. 294). In the original specimen the total rare earths plus thorium oxide equaled 72.71 percent of the weight of the monazite (H. J. Rose, Jr., oral commun., 1958). The published analysis is recalculated below to total 72.71 percent for comparison with the other analyses:

	Percent
La_2O_3	19.93
CeO_2	38.51
Pr_6O_{11}	3.08
Nd_2O_3	8.32
Sm_2O_3	.86
Gd_2O_3	(1)
Y_2O_3	(2)
ThO_2	2.01
Total	72.71

1 < 0.3 percent in precipitate.
2 < 0.1 percent in precipitate.

Monazite was reported as questionably present in porphyritic quartz monzonite and in metasomatically altered inclusions in the Rock Corral area of San Bernardino County (Walker and others, 1956, p. 23–24; Moxham and others, 1955, p. 111–116). The occurrences are about 53 miles east-northeast of San Bernardino in an area underlain by biotite gneiss, siliceous metasedimentary rocks, and dark metavolcanic rocks of Precambrian age. Porphyritic quartz monzonite of pre-Cretaceous age intrudes the metamorphic rocks and contains many inclusions and roof pendants of them. Allanite, zircon, sphene, and monazite(?) are conspicuous accessory minerals in the biotitic wallrocks, in biotitic inclusions, and in biotite-rich parts of the quartz monzonite adjacent to inclusions. Allanite is the main thorium-bearing mineral in the Rock Corral area. Isolated inclusions contain as much as 7 percent of allanite.

A vein of allanite and monazite about 5–6 inches wide and 15 feet long is in biotite gneiss at the Black Dog claim 3–4 miles south of Rock Corral (Walker and others, 1956, p. 7, 23–24). Relative abundance of the two minerals has not been reported, but analyses of vein material showing 29.63 percent of RE_2O_3, 0.61 percent of ThO_2, and 0.28 percent of U_3O_8 suggests that the vein contains scant monazite or that the monazite is especially lean in thorium oxide.

The granitic rocks exposed about 4 miles east-northeast of Amboy, San Bernardino County, were said to contain accessory monazite(?) (Walker and others, 1956, p. 26).

Pegmatite at the Pomona Tile Co. quarry on the road between Old Woman Spring and Yucca Valley, San Bernardino County, contains a little monazite, allanite, euxenite, and samarskite associated with biotite and ilmenite (Walker and others, 1956, p. 24; Murdoch and Webb, 1956, p. 223). The monazite is most common along the borders of the quartz core of the pegmatite. An analysis of the rare-earth plus thorium oxide precipitate from a sample of monazite from a pegmatite at Yucca Valley, San Bernardino County, was reported by Murata, Rose, Carron, and Glass (1957, p. 148). The published analysis has been recalculated to total 60.46 percent, the original abundance of the precipitate (H. J. Rose, Jr., oral commun., 1958), and it shows a very large amount of thorium oxide:

	Percent
La_2O_3	7.49
CeO_2	17.96
Pr_6O_{11}	1.95
Nd_2O_3	6.88
Sm_2O_3	1.34
Gd_2O_3	.79
Y_2O_3	1.76
ThO_2	22.29
Total	60.46

At the Lucky Seven claim in San Bernardino County accessory allanite and monazite occur in biotitic pods in biotitic granite (Walker and others, 1956, p. 24). Fractures in the granite are coated with allanite(?) and monazite(?).

Near Copper Mountain, San Bernardino County, at the Homestretch group of claims, biotite-rich parts of a locally gneissic light-tan to pinkish-tan granite contain possible monazite. At the Steiner claims possible monazite and allanite occur along a fault in biotite schist (Walker and others, 1956, p. 24–25).

Radioactive minerals in biotite-rich parts of layers of quartz-biotite schist associated with granite gneiss and diorite southwest of the Pinto Basin, San Bernardino County, are thought to be allanite and monazite, but positive identification has not been made (Walker and others, 1956, p. 25).

Slightly altered anhedral crystals of monazite are associated with anhedral and euhedral grains of thorite disseminated in masses of hematite in a pegmatite dike in the Solo district about 12 miles south-southeast of Baker, San Bernardino County (Walker and others, 1956, p. 22). The dike consists principally of feldspar and quartz. It is only 6 inches to 3 feet wide, and the wallrocks are foliated granite.

Monazite was reported as a minor accessory mineral in granitic rocks and gneisses in Riverside County (Gary, 1942, p. 106). It occurs in typical quartz diotrite of the Cretaceous batholith in southern California (Larsen and others, 1952, p. 1046), as small euhedral crystals in tonalite exposed south of Val Verde (Wilson, R. W., 1937, p. 124, 126; Murdoch and Webb, 1956, p. 234) and in quartz diorite near the coast south of San Francisco (Hutton, 1952, p. 95). Fine-grained granite at Mt. Rubidoux near Riverside contains accessory monazite, zircon, sphene, and allanite, but coarse-grained granite at the same locality lacks monazite, although it has accessory allanite, apatite, sphene, and zircon (Larsen and Keevil, 1947, p. 491; Murdoch and Webb, 1956, p. 233; Smith and others, 1957, p. 369). Precambrian biotite gneiss is possibly monazite bearing in the vicinity of Twentynine Palms (Davis and others, 1959). Quartz monzonite in the Live Oak Tank area about 12 miles south of Twentynine Palms seems to contain monazite as does biotite gneiss at a locality about 2 miles northwest of Cactus City (Walker and others, 1956, p. 25–26).

Pegmatite dikes in Riverside County have frequently been reported to contain accessory monazite, and locally the monazite may make up as much as 0.8 percent of the pegmatite, but none of the dikes is a commercial source of the mineral (Dykes, 1933). A pegmatite dike at the William Niendorff ranch about 2 miles north of Winchester was the source of museum specimens of monazite and xenotime on crystals of black tourmaline (Symons, 1936, p. 116; Pabst, 1938, p. 205; Chesterman, 1950, p. 362; Murdoch and Webb, 1956, p. 223; Walker and others, 1956, p. 37). Monazite was reported from a pegmatite exposed in a magnesite mine near Winchester (Murdoch and Webb, 1956, p. 234). Rosettes of monazite associated with rose quartz have been reported from the Williamson silica mine (Murdoch and Webb, 1948, p. 216; 1956, p. 223). The Southern Pacific silica quarry is in a pegmatite dike in granite about 3 miles east of Nuevo and 15 miles southeast of Riverside. The dike consists mainly of quartz with small amounts of albite and orthoclase and accessory tourmaline, xenotime, and reddish-brown euhedral crystals of monazite as much as 2 inches across (Melhase, 1936; Schwartz, 1944; Chesterman, 1950, p. 362; Murdoch and Webb, 1956, p. 223; Walker and others, 1956, p. 37). Crystals of monazite were reported to have been found with albite in a pegmatite dike exposed about 600 feet west of the Jensen limestone quarry in the Jurupa Mountains (Pabst, 1938, p. 205; Chesterman, 1950, p. 362), but Murdoch and Webb (1956, p. 223) thought that the reported monazite may actually have been sphene, which is abundant at the locality. Monazite was said to occur in pegmatite dikes just east of Riverside, at the foot of Box Springs Mountain (Pabst, 1938, p. 205; Murdoch and Webb, 1956, p. 233) and at Mountain View (Murdoch and Webb, 1956, p. 234).

The Woodson Mountain granodiorite exposed northeast of Descanso Junction, San Diego County, has accessory monazite (Jaffe and others, 1959, p. 86). Monazite is also known as an accessory in the lithium-bearing Stewart pegmatite (Jahns, 1953, p. 1090), in the ABC mine at Ramona and in the Katerina mine, Hiriart Mountain, Pala (Murdoch and Webb, 1956, p. 234). Sporadic well-formed crystals of monazite are included in garnet in pegmatite at Mesa Grande (Murdoch and Webb, 1948, p. 216; 1956, p. 234; Chesterman, 1950, p. 362).

Quartz monzonite exposed near Bishop, Inyo County, has accessory monazite (Jaffe and others, 1959, p. 89).

Granite exposed in the Pacific Grove and Monterey areas, Monterey County, contains abundant accessory monazite (Hutton, 1952, p. 96; Messner, 1955, p. 138).

SANDSTONE

The sandstones of the California oil fields have been said to contain some 17 varieties of heavy accessory minerals or groups of minerals among which monazite is 11th in order of abundance, being preceeded by the amphiboles, pyroxenes, opaque metallic minerals, epidote, micas, garnet group, zircon, tourmaline, apatite, and rutile, and followed by kyanite, brookite, andalusite, topaz, corundum, and staurolite (Tickell, 1924, p. 166). Monazite was found to be of scare and sporadic occurrence in sandstones of Miocene and Pliocene age in the Kettleman Hills (Bramlette, 1934, p. 1576). Massive sandstone and conglomerate and interbedded soft sand and clay of the Sespe Formation contains sparse detrital monazite (Gianella, 1928, p. 747–748).

STREAM DEPOSITS

Monazite in some gold placers in California has been known since the early 1900's when Day and Richards investigated the mineralogical composition of black sands from placer mines along the Pacific slope of the United States (Day, 1905a, p. 5–15; 1905b, p. 19; 1907, p. 144; Day and Richards, 1906a, p. 152; 1906b, p. 1182–1191). The number of occurrences of monazite in stream sediments was scarcely increased by the investigations of radioactive deposits in the 1950's. By 1956 monazite had been observed in stream deposits at scattered localities from Imperial County in the south to Plumas County in the north, but placer monazite has not been produced commercially (Gary, 1942, p. 106).

Monazite was said to occur in placers in the Ogilby district, Imperial County (Walker and others, 1956, p. 37). It is found in sediments of the San Joaquin River near Friant, Fresno County, the Merced River in Merced County, and the Tuolumne River near La Grange and the Stanislaus River in Stanislaus County (Wright, 1950, p. 3; Walker and others, 1956, p. 37).

Thorium- and cerium-bearing ore, possibly monazite, was reported to have been found at a gold mine on Indian Creek near Sheep Ranch about 14 miles north of Angels Camp, Calaveras County (Miner, 1929); however, the mineralogy was not discussed. At Placerville and in the Indian Diggings, El Dorado County, the black sands from gold placers contain a trace of monazite (Day and Richards, 1906b, p. 1184–1185; Pabst, 1938, p. 205; California Mining Jour., 1946). Traces of monazite have been observed in placers at Loomis and at Michigan Bluff, Placer County (Day and Richards, 1906b, p. 1186–1187). Black sands containing 4 pounds of monazite, 632 pounds of chromite, and 844 pounds of ilmenite per short ton were found at Rough and Ready in Nevada County (Day and Richards, 1906b, p. 1186–1187). In Yuba County traces of monazite occur in concentrates from placers at Marysville and the Brownsville district (Day, 1905a, p. 19; Day and Richards, 1906a, p. 152; 1906b, p. 1190–1191; Gary, 1942, p. 106; California Mining Jour., 1946; Wright, 1950, p. 3). Traces of monazite were reported in magnetite-rich concentrates from gold placers at Little Rock Creek in Butte County (Day and Richards, 1906b, p. 1182–1183; Pabst, 1938, p. 205; Murdoch and Webb, 1948, p. 216). Concentrates from a gold placer at an unspecified locality in Plumas County were said by Day and Richards (1906b, p. 1186–1187) to contain 10 pounds of monazite, 1456 pounds of magnetite, and 376 pounds of ilmenite per short ton. A later report identified the Plumas County locality as Nelson Point (Pabst, 1938, p. 205).

In the early 1950's the U.S. Bureau of Mines investigated monazite in streams in Yuba, Stanislaus, and Sacramento Counties, and in the beach sands in Monterey County. The results of these studies have not been published, but they were summarized by Eilertsen and Lamb (1956, p. 11–13). Only small amounts of black sand, principally magnetite, were found in the fluvial placers. The magnetite was accompanied by sparse to very sparse garnet, zircon, and epidote, and by trace amounts of monazite and uranothorite. Beach sands at the Monterey Peninsula were also found to contain only trace amounts of monazite.

The reports on monazite in stream placers in California are largely restricted to the pioneering work of Day and Richards on the accessory minerals in the black sands of gold placers. No independent regional search for fluviatile monazite placers has been made. Direct evidence to support the widely held contention that fluviatile monazite deposits of any size are lacking in California is most inadequate, because no real search has been made for them, and the results of the studies by Day and Richards have been generally accepted. It is common, however, for gold deposits to be found in areas lean in or devoid of monazite. Until a study of streams draining areas underlain by plutonic rocks of high metamorphic grade has been made, the presence of fluviatile monazite placers in California cannot be said to be disproved. Indirect evidence seems to support the idea that monazite is in general sparse in the rocks in California. It is very uncommon in the sandstones in the oil fields, and it is not especially abundant on the beaches.

BEACH DEPOSITS

Monazite occurs in beach deposits along the Pacific coast of California at Del Norte and Humboldt Counties in the extreme northern part of the State and in San Mateo, Santa Cruz, and Monterey Counties in the central part of the State. It is fine grained and variable in its occurrence but was regarded by Day (1907, p. 144) as possibly easier to recover and more abundant than that in the placers in North and South Carolina. By 1918, however, the economic value of the Pacific coast placers was overshadowed by the discovery of large and easily exploitable deposits in India, and the California placers had come to be regarded as having no commercial use (Hornor, 1918, p. 35–37). It is likely that this opinion is still justified, particularly in view of the low tenor in ThO_2, 3.5–4.4 percent, reported for monazite from beach placers south of San Francisco.

Black sand from Crescent City in Del Norte County was found by Day and Richards (1906a, p. 152; 1906b, p. 1184–1185) to contain 56 pounds of monazite per short ton of concentrate:

	Tenor (lb. per short ton)
Magnetite	481
Chromite	209
Garnet	503
Olivine	574
Monazite	56
Zircon	44
Quartz	133
Total	2,000

Sand from Gilbert Creek north of the Smith River, Del Norte County, contained only 0.12 pound of monazite per short ton and was also lean in magnetite, chromite, garnet, olivine, and zircon (Day and Richards, 1906a, p. 152). At Trinidad in Humboldt County a trace of monazite was observed in black sand (Day and Richards, 1906b, p. 1184–1185).

Beach sands from localities along the Pacific coast between Princeton Beach, San Mateo County, and Pacific Grove, Monterey County, were studied by Hutton (1952, p. 8–55; 1953, p. 6–19). He found the natural concentrations of beach sands were very common along this part of the coast but that the zones of concentration were generally short, thin, and impermanent. Local concentrations of a more permanent character were observed in the backshore zones of beaches at or near the south side of headlands that could interrupt the southward drift of the ocean current. Concentrations were also observed at the south side of the mouths of streams. Relatively stable monazite-bearing deposits of black sand occur at Princeton Beach, the mouth of the Tunitas River, south of Pigeon Point Lighthouse, and just east of Point Año Nuevo, San Mateo County. In Santa Cruz County they occur on the south side of the mouth of Año Nuevo Creek and at the mouth of the Pajaro River. In Monterey County, monazite-bearing relatively permanent deposits were reported by Hutton (1952, p. 9) to occur at Marina Beach and Pacific Grove.

Dune deposits containing large deposits of monazite-bearing black sand were formed in the vicinity of the mouth of the Pajaro River at the boundary between Santa Cruz and Monterey Counties (Hutton, 1952, p. 11).

The mineralogical composition of the beach and dune sands is very complex. Hutton (1952, p. 12a) listed about 50 minerals and varieties of minerals in the full group of concentrates. Most samples contained about 30 different minerals, of which augite, chromite, clinozoisite, epidote, garnet, hornblende, hypersthene, opaque grains, rutile, sphene, and zircon are the most common. Relative abundances of the minerals were given according to the scale of Evans, Hayman, and Majeed (1934, p. 41). Recalculation from this scale shows that monazite makes up from 1 to 6 percent of the heavy minerals in the less than 250 mesh and less than 115 but greater than 250 mesh fractions of the concentrate and ½ to 1 percent of the less than 60 but greater than 115 mesh and less than 32 but greater than 60 mesh fractions. Monazite from the beach sands forms flat subhedral grains generally devoid of inclusions (Hutton, 1952, p. 49–50).

Two separates of monazite from black sand south of the mouth of Año Nuevo Creek, Santa Cruz County, and from dune sand at Pacific Grove, Monterey County, were chemically analyzed and found to be very similar in composition and to have only 3.49 and 3.9 percent of ThO_2 and a specific gravity at 22°C of 5.21 ± 0.02 (Hutton, 1952, p. 51):

[Analysts: *A*, Atomic Energy Comm.; *B*, Hutton (1952)]

	Percent *A*	Percent *B*
Ce_2O_3 (group)	64.8	63.9
Y_2O_3 (group)	.5–1.0	1.1
ThO_2	3.49	3.9
U_3O_8	.25	.2
P_2O_5	27.77	28.2
SiO_2	.81	.9
Al_2O_3	------	.15
Fe_2O_3	.11	.2
TiO_2	.04	.04
CaO	.47	.7
MgO	------	.1
Pb	.018	<.01
Cu	.007	[1].09
MnO	------	Trace
H_2O-	.35	.15
H_2O+		0(?)
Total	98.715	99.64

[1] CuO.

A. Del Monte Properties, Pacific Grove, Monterey County.
B. South of the mouth of Año Nuevo Creek, Santa Cruz County.

The rare-earth plus thorium oxide precipitate from the monazite from Pacific Grove was analyzed spectrochemically and the results, recalculated to 62.3 percent of RE_2O_3 plus ThO_2 in the monazite (H. J. Rose, Jr., oral commun., 1958) show 4.4 percent of ThO_2 in the monazite:

[Analysts: Murata, Rose, and Carron (1953, p. 294)]

	Percent
La_2O_3	13.6
CeO_2	26.6
Pr_6O_{11}	2.8
Nd_2O_3	10.7
Sm_2O_3	1.7
Gd_2O_3	.6
Y_2O_3	1.9
ThO_2	4.4
Total	62.3

COLORADO

Monazite in Colorado apparently was first noted in the early 1900's in placer concentrates (Day, 1905a, p. 9; Day and Richards, 1906b, p. 1190–1193), although allanite had been widely observed in crystalline rocks in the State by 1885 (Iddings and Cross, 1885, p. 111). Reports of monazite in the crystalline rocks first begin to appear as a result of the pegmatite investigations of the early 1940's and mainly refer to mineral occurrences. The search for radioactive deposits in the 1950's turned up further minor occurrences in the crystalline rocks, but more importantly, it disclosed large fossil placers in sandstone of Late Cretaceous age. One of the significant implications of the fossil placers is that monazite must be a more common minor accessory mineral in the old schists and gneisses than it is now known to be.

CRYSTALLINE ROCKS

The principal occurrences of monazite in crystalline rocks have been reported from Larimer County south to Saguache County. Most of these are in pegmatites and are of no economic consequence.

Pegmatite dikes associated with granite in the vicinity of the Copper King mine, Larimer County, were reported to contain monazite (Phair and Antweiler, 1954, p. 93). Pegmatite dikes in the Park Range, Routt County, have accessory monazite, seemingly of a rather low tenor in thorium oxide because the alpha count of this monazite is low (Jaffe and others, 1959, p. 128).

Monazite from Boulder County is known as a minor accessory mineral in pegmatite dikes related to the Silver Plume Granite at Jamestown (Hanley and others, 1950, p. 21; Heinrich and Bever, 1957, p. 11). At the Rusty Gold cerite prospect on Central Gulch about 2 miles northeast of Jamestown, monazite and other rare-earth minerals are associated with cerite in the potassium feldspar core of a zoned and banded body of biotite-muscovite pegmatite 30 feet long and 2–5 feet thick. The core zone reaches a maximum thickness of 16 inches and contains from 2 to 5 percent of RE_2O_3 in very fine grained aggregates dominantly composed of cerite and allanite with which small quantities of bastnaesite, toernbohmite, monazite, and uraninite occur. Aplitic phases bearing monazite are also known.

The composition of the rare-earth and thorium oxide precipitate from monazite from an aplite-pegmatite vein in the Jamestown area, Colorado, was analyzed spectrochemically (Murata and others, 1957, p. 148) and found to be lean in thorium oxide. Recalculated to 68.08 percent, the abundance of the rare earths and thorium oxide in this monazite (H. J. Rose, Jr., 1958, oral commun.) is as follows:

	Percent
La_2O_3	8.57
CeO_2	27.06
Pr_6O_{11}	3.98
Nd_2O_3	21.46
Sm_2O_3	2.90
Gd_2O_3	1.28
Y_2O_3	1.89
ThO_2	.94
Total	68.08

Migmatitic biotite paragneiss at three localities near Central City, Gilpin County, contains minor accessory monazite and xenotime and local concentrations of these minerals (Young and Sims, 1961, p. 276–296). The concentrations range from 1 to 5 percent of the volume of the rock in biotite-rich zones which have a maximum thickness of 5 feet and are several hundred feet long. Prospected localities are at Jasper Cuts about a mile south-southeast of Central City, Fourmile Gulch about three-fourths of a mile northeast of Black Hawk, and at Illinois Gulch about a mile south-southwest of Central City. At Jasper Cuts about 100 short tons of rock was mined in 1957 as an ore for the yttrium earths (Young and Sims, 1961, p. 277).

The concentrations of xenotime and monazite are about 100 feet stratigraphically above the base of an intimately interlayered sequence of migmatitic biotite-quartz-plagioclase gneiss and biotite-sillimanite-quartz gneiss, which overlies microcline-quartz-plagioclase gneiss. The biotitic and sillimanitic gneisses are interlayered with about equal amounts of pegmatite.

At each of the three localities the xenotime and monazite occur as aggregates of sand-size subrounded to rounded grains in thin biotite-rich layers. Biotite in these layers is coarse grained, and the flakes are randomly oriented in contrast to the strong preferred orientation of the biotite in the rest of the gneiss. The aggregates of xenotime and monazite are accompanied by small amounts of magnetite and zircon, but the large and varied suites of heavy minerals commonly associated with placers are not present. A more varied suite of heavy minerals is present in the gneiss than in the xenotime and monazite-rich layers.

The concentrations of monazite and xenotime were interpreted by Young and Sims (1961, p. 294–296) to have formed in place late in a period of Precambrian deformation and migmatization. The pegmatite, which constitutes the felsic phase of the migmatitic paragneiss, was thought to have formed from the gneiss during plutonic metamorphism at the upper amphibolite grade and to have mobilized the rare earths and phosphate in the biotite gneiss. These components crystallized with the unoriented biotite late in the deformation of the gneiss. Other geologists have explained the concentration of monazite as a hybrid process involving the formation of migmatite by pervasive injection of pegmatitic and granitic material into paragneiss with an implicit conveyance of rare-earth minerals from some igneous source (Heinrich, 1958, p. 270). No known igneous source exists for the monazite and xenotime in the migmatite because, according to Young and Sims (1961, p. 295), intrusive granodiorite in the Central City area lacks both of these minerals, and the biotite-muscovite granite in the area, though monazite bearing, was introduced after the monazite was formed.

Monazite is a minor accessory mineral in tabular, locally zoned pegmatite dikes and sills in migmatite in the Clear Creek pegmatite district of southeastern Gilpin County, northeastern Clear Creek County, and northwestern Jefferson County (Hanley and others, 1950, p. 29–30; Boos, 1954, p. 124; Heinrich and Bever, 1957, p. 11). Common major accessory minerals are muscovite, biotite, beryl, tourmaline, and garnet, and the other minor accessories are chrysoberyl, apatite, magnetite, bertrandite, columbite, rutile, samarskite, pyrite, molybdenite, gadolinite, and fluorite. In the Soda Creek–Beaver Brook part of the district at least one of the bodies of monazite-bearing pegmatite also contains accessory topaz and amazonstone.

A monazite-bearing granite pegmatite dike at Centennial Cone, Jefferson County, intrudes granitic gneiss and mica schist (Waldschmidt and Adams, 1942, p. 29–30; Hanley and others, 1950, p. 85–86). The contacts between the dike and its wallrocks are sharp, and the walls are unaltered. The dike is about 10 feet thick and 500 feet long. For most of its length it is composed simply of quartz, microcline, and sparse muscovite, but the intermediate zone of the dike, about 40 feet long and no more than 6 inches thick, is mineralogically complex and contains beryl, monazite, albite, bertrandite, sericite, garnet, samarskite, molybdenite, and biotite. Monazite is relatively abundant in crystals as much as 1½ inches long in the mineralogically complex part of the dike (Waldschmidt and Adams, 1942, p. 32). Irregular dark-brown unidentified inclusions in the monazite suggest that the monazite formed from an earlier precipitated mineral. Most of the coarse crystals of monazite are partly embedded in beryl, but fine-grained monazite occurs as both inclusions in and encrustations on crystals of beryl. Apparently the crystallization of beryl was interrupted by a period in which monazite, garnet, samarskite, muscovite, and molybdenite precipitated, and this period was followed by a sparse second deposition of monazite upon existing beryl crystals.

The well-zoned Bigger mica-beryl pegmatite dike in the Sweitzer Gulch–Twin Forks area of Jefferson County cuts across and is locally conformable to the foliation of a mass of gneissic diorite (Hanley and others, 1950, p. 82–83; Boos, 1954, p. 124). The dike is composed of potassium feldspar, quartz, muscovite, and sparse albite and biotite. Accessory minerals are minor beryl, tourmaline, garnet, bismuthinite, bismutite, sulfides, monazite, columbite and tantalite. Euhedral crystals of monazite as much as 0.5 inch across are associated with black tourmaline in the intermediate zone of the dike. This zone is about 2 feet thick and at least 320 feet long.

Monazite is a rare accessory mineral in unzoned and zoned pegmatite dikes in the South Platte area, Douglas County (Heinrich and Bever, 1957, p. 11). Other rare accessory minerals are beryl and columbite. Minor accessory minerals are bismuthinite, bismutite, tourmaline, and pyrite, and major accessory minerals are muscovite, biotite, and fluorite.

The Guffey-Micanite area in the southeastern part of Park County and the north-central part of Fremont County is underlain by biotite schist, quartz-feldspar-biotite gneiss, quartz-sillimanite schist, amphibolite, and granite. Zoned dikes of granitic pegmatite in these rocks have a wide variety of accessory minerals among which monazite is one of the least common. These minerals include muscovite, biotite, beryl, garnet, apatite, columbite, tourmaline, magnetite, bismutite, beyerite, cordierite, pinite, sillimanite, monazite, euxenite, and doubtful uranothorite (Hanley and others, 1950, p. 43; Bever, 1952; Heinrich and Bever, 1957, p. 12–13, 25–30, 32). Locally the monazite is intergrown with euxenite or closely associated with beryl, columbite, and muscovite.

At the Boomer mine near Lake George in Park County, monazite was found in a beryl-quartz-fluorite vein in biotite gneiss adjacent to a body of granite (W. R. Griffitts, oral commun., 1960). Small monazite crystals are perched on crystals of beryl in a cavity surrounded by beryl.

Byproduct monazite, topaz, pyrite, tin, and tungsten minerals were recovered from the ore body at the Climax molybdenum mine in Lake County (Eng. and Mining Jour., 1951). Only about 0.005 percent of monazite is present in the ore.

A diorite intrusive in sandstone and shale of Pennsylvanian age and limestone of Mississippian age at the Calumet Iron Mine, Chaffee County, has produced a corundum-andesine-sillimanite assemblage in the shale and asbestiform diopside, actinolite, tactite, and garnet in the limestone. Vuggy masses of epidote in the contact zone were reported to be cemented by white scapolite or topaz, and crystals of monazite occur in the cavities perched on the scapolite or topaz (W. R. Griffitts, oral commun., 1960).

The Yard mine about 4 miles northeast of Buena Vista in the Trout Creek–Pass area, Chaffee County, exposes a body of monazite-bearing pegmatite about 200 feet long and 50 feet wide in coarse-grained granite to which the pegmatite was said to be genetically related (Hanley and others, 1950, p. 21–22). Quartz, microcline, and sericitized plagioclase are the chief constituents of the pegmatite and have the remarkable average grain size of about 6 feet. Accessory minerals are biotite, muscovite, monazite, and euxenite, of which monazite and euxenite are sparsely and erratically distributed. Monazite forms subhedral to anhedral masses as large as 8 inches across. Other pegmatite dikes in the area contain small quantities of bismuth minerals, allanite, and euxenite, but monazite was unreported (Hanley and others, 1950, p. 22).

Monazite is a minor accessory mineral in 23 (1.3 percent) of the 1,803 pegmatite dikes in the Quartz Creek pegmatite district, Gunnison County (Wemlinger, 1950, p. 92; Heinrich, 1953, p. 77; Staatz and Trites, 1955, p. 28). The pegmatite dikes for the most part occur in granite, quartz monzonite, and hornblende gneiss. The composition of the host rocks has had little effect on the shape of the bodies of pegmatite, but the degree of competency of the hosts does. Most of the dikes lack or have only poorly differentiated zones and internal structures, but some are layered and a few are strongly zoned (Hanley, 1946; Hanley and others, 1950, p. 19; Jahns, 1953, p. 1090). Wallrocks are virtually unaltered at the contacts with the pegmatite dikes, and the dikes are especially lean in tourmaline, apatite, and other minerals indicative of volatile components. These observations were interpreted by Staatz and Trites (1955, p. 45) as indicating that boron, phosphorus, and water were present in the small amounts needed to form the rare accessory minerals but not in surplus amounts. The dikes were thought to have formed by fractional crystallization in place.

In the pegmatite dikes, monazite occurs as dark-red to brown euhedral crystals from a quarter of an inch to 2 inches in length (Staatz and Trites, 1955, p. 40). It is most common in the feldspar-rich parts of the few dikes in which it is found. In most of the dikes less than six grains of monazite were observed, but a dike at the Brown Derby mine contains a unit 20 feet long and a foot wide that has 2.2 percent of monazite. Elsewhere in the district exceptional local concentrations of monazite were observed at the Black Wonder pegmatite and Bucky pegmatite. Monazite from the Brown Derby mine contains 5.62 percent of ThO_2 and 0.16 percent of U_3O_8 (Tilton and Nicolaysen, 1957, p. 31).

Several thorium- and rare-earth-bearing minerals have been found in veins and mineralized shear zones near an alkalic igneous complex in the Powderhorn district of Gunnison County, but monazite has only been found in a few carbonatite dikes within the complex (Hedlund and Olson, 1961, p. B283; Olson and Wallace, 1956, p. 693–703; Jarrard, 1957, p. 42).

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Pegmatites in the Villa Grove area and in the area near Crestone, Saguache County, contain monazite, euxenite, and cyrtolite (Brown and Malan, 1954, p. 11–14).

FOSSIL PLACERS

Fossil placers composed of ilmenite and accessory monazite, garnet, zircon, tourmaline, magnetite, rutile, and several unidentified opaque minerals occur intermittently in the upper parts of littoral marine sandstone of Late Cretaceous age in the San Juan basin, Colorado and New Mexico (Chenoweth, 1956; 1957, p. 212), and in sedimentary rocks of the same age in Wyoming and Montana (Murphy and Houston, 1955, p. 190–194). Outcrops of the fossil placers are discontinuously exposed for at least 700 miles subparallel to the Rocky Mountains. This distribution of detrital monazite is here interpreted to indicate that the mineral is much more widely present in the plutonic rocks of the Rocky Mountains than the literature indicates. These fossil placers may contain Colorado's largest known resources in monazite.

The most northerly of the reported deposits in Colorado is on the flank of Grand Mesa, about 20 miles east of Grand Junction, Mesa County (Murphy and Houston, 1955, p. 190). The other reported deposits are in Montezuma County in the southwestern part of the State and extend intermittently southeastward from the vicinity of Mesa Verde to Shiprock, N. Mex. (Chenoweth, 1957, p. 213). As in Wyoming and New Mexico the deposits in Colorado are ancient beach placers at transitions between marine and nonmarine sedimentary rocks. They are in well-sorted marine sandstone which is overlain by lagoonal deposits of coal and shale (Chenoweth, 1957, p. 212).

In the San Juan basin the placers range in length from a few tens to several thousands of feet and in width from a few tens to several hundreds of feet (Chenoweth, 1957, p. 213). They are fine grained, well sorted, and are cemented with hematite and limonite. From 50 to 60 percent of the placer sand is heavy minerals, dominantly ilmenite, and the remainder is quartz. In the heavy fraction the general distribution of minerals is 62–77 percent of ilmenite, 15–20 percent of zircon, 5–15 percent of garnet, and about 3 percent of various mixtures of monazite, rutile, spinel, epidote, amphibole, magnetite, and tourmaline.

Fourteen fossil placers were reported in the Point Lookout Sandstone by Chenoweth (1957, p. 215–216) in the area between Mesa Verde, Colo., and Shiprock, N. Mex., five being in Colorado. None is well exposed, but one deposit crops out intermittently for 2¾ miles. It reaches 250 feet in width and 6 feet in thickness.

PRESENT STREAM PLACERS

Monazite was listed as a component of black sands from streams, mainly gold bearing, at Hahns Peak and Timber Lake, Routt County (Day and Richards, 1906b, p. 1192–1193; Sanford and Stone, 1914, p. 46; Schrader and others, 1917, p. 91). Only a trace of monazite was found in the concentrate from Hahns Peak, but two concentrates from Timber Lake were remarkably rich in monazite (Day and Richards, 1906b, p. 1192–1193):

	Pounds per short ton	
	A	*B*
Magnetite	128	-------
Ilmenite	792	584
Garnet	448	512
Monazite	416	520
Zircon	Trace	80
Quartz	196	304
Total	1, 980	2, 000

This tenor of monazite in stream placers in the Western States, as reported by Day and Richards, is only equaled by two samples from Timber Lake, Colo., two samples from the Elk City district, Idaho, and a sample from Big Creek, Idaho. A trace of monazite is present in concentrates from the Central City area, Gilpin County (Day and Richards, 1906b, p. 1192–1193).

Monazite was said to occur in gold placers at Newlands Gulch and the Platte Canyon in Douglas County about 20 miles south of Denver (Kithil, 1915, p. 13).

At Buena Vista in Chaffee County, black sands lean in or barren of gold were reported by Day and Richards (1906b, p. 1190–1193).

Mineralogical composition, in pounds per short ton, of concentrate from Buena Vista

	A	*B*	*C*
Magnetite	1, 012	1, 248	1, 472
Ilmenite	186	462	168
Garnet	28	83	80
Hematite	--------	--------	168
Olivine	--------	3	--------
Monazite	20	28	32
Zircon	--------	82	56
Quartz	664	68	24
Unidentified minerals	90	22	--------
Total	2, 000	1, 996	2, 000

Concentrates from the San Lina Valley and the San Luis Valley, Costilla County, contain monazite (Schrader and others, 1917, p. 91). That from the San Luis Valley has only a trace, but the concentrate from the San Lina Valley contains 30 pounds of monazite per short ton (Day and Richards, 1906b, p. 1192–1193):

	Pounds per short ton
Magnetite	1, 008
Chromite	452
Ilmenite	500
Monazite	30
Zircon	10
Total	2, 000

CONNECTICUT

Monazite was identified in 1837 by C. U. Shepard in sillimanite gneiss exposed at the falls of the Yantic River in Norwich, New London County (Shepard, 1837a, p. 163; 1840, p. 249; 1852, p. 109; Beck, 1842, p. 452; Silliman, 1844), and in pegmatite at Watertown, Litchfield County (Shepard, 1837b, p. 342; Beck, 1842, p. 450). These seem to be the first reported occurrences of monazite in the United States. By 1852 monazite was known in gneiss at Chester in Middlesex County (Silliman, 1844, p. 207) and at Litchfield in Litchfield County (Shepard, 1852, p. 109). Since that time monazite has been found in about 24 pegmatite dikes (Pratt, 1905, p. 41; Dale and Gregory, 1911, p. 3; Sanford and Stone, 1914, p. 53; Schrader, Stone, and Sanford, 1917, p. 100; Schairer, 1931, p. 55; Dake, 1955, p. 55), in old gneisses (Mining and Sci. Press, 1902) and in sandstone of Triassic age (Krynine, 1950, p. 23). Practically the entire literature on monazite in the State relates to the mineralogical occurrences in the pegmatite dikes. Economic deposits of monazite are unknown in the crystalline rocks, and the streams draining the glaciated uplands are unlikely to have had access to enough monazite since the last glaciation to have formed placers.

PEGMATITE

Most of the reported occurrences of monazite in Connecticut are in the Middletown pegmatite district (Cameron and others, 1954, p. 5) in Hartford and Middlesex Counties. These pegmatite dikes have been said to be genetically related to the Monson Gneiss of granodioritic to granitic composition (Foye, 1949, p. 51), which occurs as bodies of variable size in staurolite- and kyanite-bearing mica schist, but the genetic relationship seemingly is not firmly established (Rodgers, 1952, p. 415). There is a strong tendency for the pegmatite dikes to be more abundant in schist adjacent to the Monson Gneiss than in the gneiss itself (Foye, 1922, p. 4). Some dikes cut across the contact between the schist and gneiss.

Dikes in the Middletown district tend to be flat, bluntly terminated, elongate lenticular bodies having well-defined mineralogical zoning parallel to the walls (Cameron and others, 1954, p. 2; Heinrich, 1953, p. 74–75). From the walls inward the mineralogical zones comprise a quartz-muscovite-plagioclase border zone, a quartz-plagioclase-sheet muscovite zone, a plagioclase-perthite-quartz-muscovite zone with or without biotite, a perthite-quartz-plagioclase-muscovite zone with or without biotite, a perthite-quartz zone, and a quartz core. All zones are rarely present in a single dike, and in some dikes, material of the inner zones is found to fill fractures in the outer zones. According to Cameron, Larrabee, McNair, Page, and Stewart the zonal mineralogical sequence in the dikes can best be interpreted as successive crystallization inward from the walls and not as replacement of existing massive pegmatite.

A large number of minor accessory minerals occur in the pegmatite dikes of the Middletown district. Beryl, gahnite, lepidolite, cookeite, spodumene, magnetite, garnet, tourmaline, chrysoberyl, triplite, triphylite, lithiophilite, monazite, zircon, bismutite, columbite, samarskite, microlite, epidote, uraninite, autunite, molybdenite, and sphalerite have been reported (Heinrich, 1953, p. 74–75; Rice and Gregory, 1906, p. 73). Monazite is not an especially abundant accessory in the Middletown pegmatite district, but it has been reported from dikes near Glastonbury, Hartford County (Rice and Gregory, 1906, p. 73; Foye, 1949, p. 51; Sohon, 1951, p. 50), and Portland and Haddam, Middlesex County. Of the pegmatite occurrences in Middlesex County those near Portland have been described most extensively in the literature.

Three feldspar quarries and a beryl prospect at Portland are monazite bearing. The Strickland or Collins Hill quarry 2.5 miles northeast of the center of Portland exposes one of several pegmatite dikes in staurolite- and kyanite-bearing muscovite-biotite schist (Rice and Foye, 1927, p. 83–87; Schairer, 1931, p. 55; Foye and Lane, 1934, p. 130, 137; Jenks, 1935, p. 177, 181–184; Zodac, 1937, p. 134–141). The Strickland quarry is in coarse-grained pegmatite and associated graphic granite.

The Pelton quarry east of the Strickland quarry opens a body of pegmatite in orthogneiss (Foye, 1922, p. 4). The pegmatite contains minor cinnamon-brown accessory monazite (Penfield, 1882, p. 250–251; Dana, 1884, p. 543; Schairer, 1931, p. 55). Two analyses of monazite from the Pelton quarry made by Penfield (1882, p. 252) showed a specific gravity of 5.20–5.25.

Chemical analyses, in percent, of monazite from the Pelton quarry

	A	B	Mean
Ce_2O_3	33.69	33.40	33.54
$(La, Di)_2O_3$	28.15	28.51	28.33
ThO_2	8.33	8.17	8.25
P_2O_5	28.19	28.16	28.18
SiO_2	1.57	1.77	1.67
Loss on ignition	.36	.38	.37
Total	100.29	100.39	100.34

Dull brownish-red monazite crystals nearly an inch long are in pegmatite at the Hale quarry, also known as the Andrews quarry, north of the Strickland quarry and north of Portland (Rice, 1885; Foye, 1922, p. 6; Schairer, 1931, p. 55; Foye and Lane, 1934, p. 130). The quarry is in a large dike of pegmatite and graphic granite in orthogneiss (Zodac, 1941, p. 166–167). A large variety of minerals have been found in the dike, but most of them are minor accessories. The list as compiled by Zodac (1941, p. 166–167) includes albite, allanite, apatite, autunite, beryl, biotite, chalcopyrite, columbite, garnet, limonite, melanterite, microcline, molybdenite, monazite, montmorillonite, muscovite, pyrite, pyrolusite, pyrrhotite, quartz, sphalerite, torbernite, triphylite, tourmaline, uraninite, xenotime, and zircon.

A crystal of monazite from the Hale quarry was analyzed by Fenner (1932, p. 330; Lane, 1932, p. 16) and found to contain 0.00 percent of U_3O_8, 8.52 percent of ThO_2, and 0.1086 percent of PbO. Monazite from Portland, possibly from the Strickland quarry or from the Hale quarry, was shown by Boltwood (1905, p. 608, 611) to have 8 percent of ThO_2 and 0.3 percent of U_3O_8.

Monazite from Portland, locality not otherwise identified, was found to contain 10.8 percent of ThO_2 after the analysis was recalculated to 68.3, the sum of the rare earths and thorium oxide in the monazite (H. J. Rose, Jr., oral commun., 1958):

[Analysts: Murata, Rose, and Carron (1953, p. 294)]

	Percent
La_2O_3	12.9
CeO_2	23.8
Pr_6O_{11}	2.7
Nd_2O_3	9.8
Sm_2O_3	4.4
Gd_2O_3	2.1
Y_2O_3	1.8
ThO_2	10.8
Total	68.3

The Hale-Walker beryl prospect is in a tabular body of pegmatite 180 feet long and 6–8 feet thick near Portland (Cameron and others, 1954, p. 324). The dike cuts across the foliation of the Monson Gneiss.

Quartz and perthite are the principal minerals composing the dike. Subordinate plagioclase and muscovite and accessory beryl, tourmaline, columbite-tantalite, and scarce monazite are present.

Monazite was reported to occur in a pegmatite dike in cordierite- and sillimanite-bearing biotite gneiss at Haddam, Middlesex County (Rice and Gregory, 1906, p. 73; Heinrich, 1950a, p. 178). The pegmatite consists of quartz, microcline, and albite, and has accessory tourmaline, garnet, zircon, columbite, bismutite, chrysoberyl, muscovite, epidote, biotite, monazite, and uraninite.

Branford, New Haven County, was cited as a monazite locality (Sohon, 1951, p. 50), but the nature of the occurrence was not specified. Several railroad cuts near Lyme, New London County, were said to expose monazite-bearing rocks, but the rock was not described (Schairer, 1931, p. 55; Sohon, 1951, p. 50).

Quartz-orthoclase pegmatite at South Lyme, New London County, contains accessory monazite, sphene, tourmaline, molybdenite, and biotite (Matthew, 1895, p. 231–232; Kemp, 1899, p. 374; Loughlin, 1912, p. 127; Sohon, 1951, p. 50). The monazite tends to occur close to and in books of biotite. Monazite is present in pegmatite in the vicinity of Waterford, New London County (Schairer, 1931, p. 55; Sohon, 1951, p. 50).

Monazite occurrences at Willimantic and Windham, Windham County, have been mentioned, but the kind of occurrence was not specified (Sohon, 1951, p. 50). Good crystals of monazite were reported from Oneco, Windham County, but the source was not described (Schairer, 1931, p. 55).

OTHER PLUTONIC ROCKS

Sillimanite schist exposed just downstream from Yantic Falls near Norwich in New London County has long been known to contain accessory monazite (Shepard, 1837a, p. 163; Schairer, 1931, p. 55; Foye, 1949, p. 83).

Granite in the Flatrock quarry 3 miles northwest of New London, New London County, has accessory monazite, sphene, ilmenite, and aeschynite (Foye, 1949, p. 83).

Alaskite associated with Sterling Orthogneiss was said to contain accessory monazite (Foye, 1949, p. 59).

SANDSTONE

Accessory detrital monazite occurs as rounded detrital grains in sandstone of Triassic age in southern and central Connecticut, particularly in the Pomperaug area, New Haven County (Krynine, 1950, p. 23, 40). The monazite ranges from almost colorless to light greenish yellow and yellowish green. Scarce inclusions consist of gas-filled cavities or dark dust. Monazite is most common in the Triassic sedimentary rocks of southern Connecticut where it reaches a maximum abundance of 4.6 percent of the heavy minerals in some sediments of the Newark Group. Other heavy detrital minerals associated with the monazite in the Triassic sediments are apatite, augite, epidote, fluorite, garnet, hornblende, kyanite, rutile, sillimanite, staurolite, sphene, tourmaline, xenotime(?), zircon, and zoisite (Krynine, 1950, p. 90–91).

DELAWARE

Monazite was said by Nininger (1956, p. 156) to occur in buried fossil beach and bar deposits that formed during Cretaceous and Tertiary time along the Atlantic seaboard as far north as Delaware, but specific localities in Delaware were not given.

FLORIDA

Detrital monazite is present in very small amounts in sand throughout much of Florida (Carpenter and others, 1953, p. 789). It is more or less concentrated locally in raised spits, beaches, and dunes in eastern and northeastern Florida. It is widely distributed as a minor component of the heavy minerals in present beaches and dunes along the Atlantic coast and in present beaches and deltas along the gulf coast of Florida (Tyler, 1934, p. 3, 7; Jones, W. H., 1949a, p. 457; Lamcke, 1940, p. 89; Casperson, 1948; Trumbull and others, 1948, p. 46–47). The monazite is associated with ilmenite, rutile, zircon, and other heavy minerals which are locally abundant enough to be mined. The principal ore minerals, ilmenite and rutile, have been mined at five localities in eastern Florida. At three of these localities byproduct monazite has been recovered (Liddell, 1917, p. 153; Calver, 1957, p. 23; Lamb, 1955a; Mertie, 1957, p. 1767; Rove, 1952, p. 141). The history of this mining is summarized below from details given by Calver (1957, p. 15–21).

Mining of the monazite-bearing beach deposits was begun by Buckman and Pritchard, Inc., in 1916 at Mineral City, now known as Ponte Vedra, St. Johns County, after exploration of the Atlantic coast from Charleston, S.C., to the Straits of Florida (Martens, 1928, p. 125). Ilmenite was the only product until 1922, except that some monazite was apparently produced around 1916 or 1917 (Liddell, 1917, p. 153). In 1922 the property was acquired by the National Lead Co., which began to recover zircon. During 1925 rutile was added to the other products, and in that year 1 short ton of monazite was said to have been produced (Santmyers, 1930, p. 11). Possibly this is the monazite reported to have been shipped from the property after World War I (Rock Products, 1929). Mining at Mineral City ceased in 1929.

In 1940 a small amount of ilmenite, zircon, and rutile was selectively mined from monazite-bearing beach sand near Melbourne, Brevard County, by the Riz Mineral Co. Shortly thereafter the company began to separate monazite from the Melbourne beach sand and to recover monazite, ilmenite, rutile, and zircon from dune sand near Vero Beach, Indian River County. After more or less continuous operation until 1946 and intermittent production to 1948 the company was reorganized under the name Florida Ore Processing Co., Inc., with a mineral separation plant at Palm Bay. Shortly after this reorganization the company began to process concentrates dredged by the Florida Minerals Co. from dune deposits just south of Vero Beach and dunes west of Winter Beach. In 1955 the Florida Ore Processing Co. discontinued mining but continued to treat the concentrates from the Florida Minerals Co. until October 17, 1955, when the Palm Bay plant burned. A new plant was put up near Winter Beach and the recovery of ilmenite, rutile, zircon, garnet, and monazite was resumed in February 1956.

A subsidiary of the National Lead Co. known as the Rutile Mining Co. of Florida began in August 1943 to recover ilmenite and rutile from monazite-bearing sand in Duval County between Jacksonville and the Atlantic Ocean. A plant designed to treat 8,000 short tons of sand per 20-hour day was erected by the Humphreys Gold Corp. under a lease from the Rutile Mining Co.; this plant began operation April 1, 1944. Only ilmenite and rutile were produced until 1946, when the recovery of zircon began. This plant has been in continuous operation since it was opened, and a small amount of monazite was said to have been produced there annually from concentrates that contained about 0.5 percent of monazite (Gunter, 1955, p. 54).

A large body of heavy-mineral-bearing sand was discovered in 1945–46 by E. I. du Pont de Nemours and Co., Inc., on Trail Ridge in the Camp Blanding area of Clay and Duval Counties southeast of Starke in the Central Highlands of Florida (Carpenter and others, 1953, p. 789). Exploration by the U.S. Bureau of Mines and the Florida Geological Survey proved that the deposit contained about 4 percent of heavy minerals. Monazite is practically absent from the heavy suite.

A part of the deposit on Trail Ridge in Clay County was opened in April 1949 for E. I. du Pont de Nemours and Co., Inc., by the Humphreys Gold Corp., which built a plant capable of treating 20,000 short tons of sand a day. Titanium minerals are the main product, but zircon is also recovered, and the separation of staurolite was begun in 1952. Sillimanite, kyanite, and andalusite are stockpiled (Browning and others, 1956, p. 2). A second and similar plant was opened for du Pont on Trail Ridge at Highland, Clay County, by the Humphreys Gold Corp. in April 1955. Monazite is not produced at either plant.

Operations at these deposits are among the largest and most modern systems for the processing of placer minerals in the United States (Thompson, J. V., 1958, p. 86). In these highly mechanized operations the ancient inland buried beach and dune deposits are preferred to the Recent beach deposits despite their lower tenor, because the ancient deposits are larger, have more uniform distribution of heavy minerals, and are not as vulnerable to severe storms. Many details of the mining and beneficiation are similar at the different properties and depend on wet-plant concentration of the heavy minerals by Humphreys spirals and dry-plant separation of monomineralic fractions by electromagnetic and electrostatic separators.

Monazite from the Florida beach placers was said by Kremers (1958, p. 2) to contain 4.5 percent of ThO_2 and 51 percent of RE_2O_3. According to Calver (1957, p. 25), the average is about 5 percent of ThO_2: analyses of five samples of detrital monazite from Amelia Island in Nassau County, Mayport in Duval County, and Ponte Vedra and Anastasia Island in St. Johns County indicated an average of 4.96 percent of ThO_2 and 0.55 percent of U_3O_8.

These values are very close to those reported for detrital monazite in stream placers at the western edge of the Coastal Plain in South Carolina. They are somewhat lower than the average abundance of thorium oxide and uranium oxide in fluvial placers in the western Piedmont of North and South Carolina. Monazite from two placers at the edge of the Coastal Plain in Aiken County, S.C., contain 5.08 percent and 5.07 percent of ThO_2 and 0.54 and 0.51 percent of U_3O_8 (Kline and others, 1954, p. 18–20; Kauffman and Baber, 1956, p. 6). The average abundance of ThO_2 and U_3O_8 in 53 samples of monazite from placers in streams in the western Piedmont of North and South Carolina was reported by Mertie (1953, p. 12) to be 5.67 and 0.38 percent.

The similarity in the amount of thorium oxide and uranium oxide in detrital monazite from Florida and South Carolina attests to the efficiency of stream transport and littoral reworking in the blending of monazite from diverse sources. The monazite in the Coastal Plain comes from crystalline rocks exposed in three well-defined belts in the Piedmont and Blue Ridge of the Southeastern States (Mertie, 1953, pl. 1; 1957). Considerable variation in the composition of monazite from different source rocks in these belts has been reported. The range in the abundance of thorium oxide in monazite from 126 samples of rock from the western Piedmont was shown in analyses by K. J. Murata and H. J. Rose, Jr. (written commun., 1958) to be 2.1–11.2 percent, and the average was 5.5. Several analyses of monazite from rocks in the Blue Ridge showed a smaller range and somewhat lower average abundance of thorium oxide. Analyses have not been made of monazite from the eastern Piedmont, but the monazite is probably not as rich in thorium oxide as that farther west. Where monazite from these diverse sources is brought together in the Coastal Plain the remarkably uniform tenor of 5 percent of ThO_2 is found. The small difference between this abundance of thorium oxide and the averages of 5.67 percent reported for fluvial placers in the western Piedmont and 5.5 percent for crystalline rocks in the western Piedmont possibly represents the influence of monazite with less thorium from the Blue Ridge and eastern Piedmont.

The near identity in the abundance of thorium oxide in detrital monazite from the Coastal Plain in Florida and in South Carolina is here tentatively interpreted to indicate that the crystalline rocks have been the source of compositionally similar monazite for a long period of geologic time and through a great depth of erosion. The detrital monazite from stream placers near the west edge of the Coastal Plain in South Carolina was originally deposited in sedimentary rocks of Late Cretaceous and Eocene age. Where exhumed by the present streams, this old detrital monazite contains the same amount of thorium oxide as detrital monazite deposited during Pleistocene and Recent time on the east coast of Florida. Possibly much of the recently deposited monazite on the Florida east coast has come rather directly from the sources in the Piedmont during Pleistocene and Recent time (Martens, 1935, p. 1594), but there seems to have been no detectable change in the aggregate composition of the monazite on the beaches from what was laid down in Late Cretaceous and Eocene time. Levels reached by Recent erosion of the crystalline rocks are, apparently, delivering monazite of similar composition to that from rocks bared at a higher erosional level during Late Cretaceous and Eocene time. The similarity in composition between monazite in the Coastal Plain of Florida and in South Carolina is here interpreted to show that interstratal solution causes little if any loss of thorium from detrital monazite.

INLAND DEPOSITS

The inland heavy-mineral deposits of northeastern Florida consist of fossil placers along Trail Ridge in Clay County and terrace and dune deposits near Jacksonville in Duval County. Two fossil placers were opened for ilmenite and other minerals on Trail Ridge, but neither has produced monazite because it is too sparse to be economically separated. It is, however, stockpiled with other unseparated heavy minerals. One of the two placers is in the Camp Blanding area of Clay and Duval Counties southeast of Starke, and the other is about 9 miles to the north at Highland in Clay County. The two deposits occupy only a small part of Trail Ridge, and the ridge is only a small part of the Central Highlands of Florida (Calvar, 1957, p. 19).

Trail Ridge was said (Carpenter and others, 1953, p. 790) to be part of an early Pleistocene spit that extended southward from Georgia during the Sunderland Stage when sea level was about 200 feet higher than present (Cooke, 1945, pl. 1). The formation of the placer deposits was related by Mertie (1953, p. 15) to concentration along the Sunderland and Coharie terraces, by Carpenter, Detweiler, Gillson, Weichel, and Wood to the construction of the spit, and by Roberts (1955, p. 52) to the formation of dunes along an ancient shoreline.

The fossil placer at Starke is a body of fine-grained sand that is 1–1½ miles wide and about 3 miles long; it is as much as 65 feet thick at the center, and has an average thickness of about 35 feet (Carpenter and others, 1953, p. 789). Underlying the placer is a dense woody layer consisting of unconsolidated carbonized branches, limbs, twigs, pine cones, and other vegetal debris mixed with clay. Under the woody layer is found coarse-grained sand devoid of heavy minerals. Carbonized organic debris is present throughout much of the placer. Below the water table the debris locally forms a tenaceous black cement that bonds sand layers and lenses ranging in thickness from a few inches to 40 feet.

The abundance of heavy minerals in the placer near Starke varies horizontally and vertically on local scale, but the average tenor of the deposit is 4 percent of heavy minerals in the raw quartz sand. Monazite was said to be present merely as a trace (Mertie, 1953, p. 15), and the average composition of the heavy suite is as follows (Calver, 1957, p. 19):

	Percent
Titanium minerals	45
Zircon	15
Staurolite	20
Sillimanite	5
Tourmaline	5
Kyanite	4
Andalusite, pyroxene, spinel, and corundum	6
Total	100

The placer on Trail Ridge at Highland was said to be similar to the deposit near Starke (Gunter, 1955, p. 43).

The Penholoway terrace of late Pleistocene age in Duval County about midway between Jacksonville and the Atlantic coast is the site of monazite-bearing raised marine and dune placers of low grade and large volume (Mertie, 1953, p. 15; Gunter, 1955, p. 54; Calver, 1957, p. 18). The raw sand contains about 4–5 percent of heavy minerals, and the concentrate was reported to have the following average composition (Calver, 1957, p. 18):

	Percent
Ilmenite	40
Leucoxene	4
Rutile	7
Zircon	11
Monazite	.5
Other minerals (mainly kyanite, sillimanite, and staurolite)	37.5
Total	100

A sample of the heads from the washing plant was reported by Miller (1945, p. 71) to contain only a trace of monazite, but monazite is recovered during processing. According to Miller the concentrate consisted of the following mineral percentages:

	Weight percent		*Weight percent*
Enstatite	24	Monazite	Trace
Epidote	11	Rutile	5
Garnet	1	Sphene	1
Hornblende	1	Staurolite	21
Ilmenite	26	Tourmaline	6
Kyanite	3	Zircon	3
Magnetite	Trace		

PRESENT BEACHES AND DUNES OF THE ATLANTIC COAST

Detrital monazite has been reported in late Pleistocene and Recent beach and dune sand at many places along the Atlantic coast of Florida from the vicinity of St. Marys Entrance in Nassau County to Upper Matacumba Key in Monroe County. The beaches, bars, and spits along the Atlantic coast are straight and wide and at many places are backed by a line of low dunes reached only by storm waves. The heavy minerals were said by Martens (1928, p. 127) to occur in striplike beds of black sand much wider than they are thick and much longer than they are wide. These beds are elongated parallel to the shoreline, and the largest beds are at the back of the beach at the foot of the dunes where they are formed by storm waves. A sequences of thin beds of dark sand generally alternates with thicker layers of light-colored beach sand. The dark layers are rarely more than 6 inches thick. They are composed of sand that is finer grained than the ordinary beach sand.

The ordinary beach sand and light-colored layers between the beds of black sand contain an average of about 0.5 percent of heavy minerals. In 17 samples of monazite-bearing light-colored sand from the Atlantic beaches the heavy minerals were reported to range from 0.01 to 2.4 percent and to average 0.48 (Martens, 1935, p. 1584). The small percentage of heavy minerals in the ordinary beach sand is dominated by ilmenite, epidote, and hornblende (table 34).

TABLE 34.—*Mineralogical composition, in frequency percent, of heavy-mineral fraction of monazite-bearing natural beach sand along the Atlantic coast of Florida*

[Modified from analyses by Martens (1935, p. 1584). Symbols used: P=0.5 percent or less; Ab, absent]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Ilmenite	42	26	27	39	28	16	41	33	30	20	32	35	39	28	33	19	30
Zircon	11	3	7	19	4	2	7	12	7	5	5	6	16	6	17	6	10
Rutile	5	3	4	4	3	2	8	5	5	5	6	5	4	4	3	1	2
Monazite	1	P	1	1	P	P	1	P	P	P	P	P	1	P	1	2	P
Epidote	18	26	22	15	26	38	21	20	23	28	20	20	20	22	25	24	21
Staurolite	7	3	3	7	5	4	4	9	10	15	20	13	7	18	4	10	10
Sillimanite	6	8	5	4	11	9	3	6	6	5	2	6	3	6	4	10	9
Kyanite	1	2	1	1	2	2	P	1	P	2	1	1	P	1	1	1	1
Hornblende	2	12	12	2	13	21	5	3	7	4	1	2	2	1	6	2	4
Tourmaline	2	3	2	4	4	3	3	6	6	11	5	7	4	6	3	21	8
Garnet	3	1	1	2	1	P	2	4	4	5	8	4	2	6	2	1	2
Collophane	P	10	P	Ab	P	P	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab
Leucoxene	1	3	2	P	3	2	6	2	1	1	1	P	1	1	2	1	3
Sphene	Ab	P	P	Ab	P	1	Ab	P	P	P	P	P	P	Ab	Ab	P	Ab
Spinel	Ab	Ab	Ab	Ab	Ab	P	Ab	Ab	Ab	Ab	Ab	P	Ab	Ab	Ab	Ab	Ab
Zoisite	P	Ab	Ab	Ab	P	P	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab
Hypersthene	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	P	Ab	Ab	Ab	P	Ab	Ab	Ab	Ab
Anatase	Ab	P	Ab	Ab	P	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab
Corundum	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	P	P	Ab	Ab	Ab
Muscovite	Ab	P	13	Ab	P	P	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	P	Ab
Andalusite	Ab	P	Ab	Ab	P	P	Ab	P	Ab	P	P	Ab	P	P	Ab	P	P
Chloritoid	Ab	P	Ab	P	P	P	Ab	Ab	P	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab

1. Amelia Island, Nassau County.
2. 200 feet south of the mouth of the St. Johns River, Duval County.
3. Manhattan Beach, Duval County.
4. Flagler Beach, Flagler County.
5. Daytona Beach, Volusia County.
6. Cocoa Beach, Brevard County.
7. Eau Gallie, Brevard County.
8. Melbourne Beach, Brevard County.
9. Fort Pierce, St. Lucie County.
10. Olympia Beach, Martin County.
11. 5 miles south of Jupiter, Palm Beach County.
12. Riviera Beach, Palm Beach County.
13. Boca Raton, Palm Beach County.
14. Hollywood Beach, Dade County.
15. 10 miles north of ship channel, Miami, Dade County.

16-17. Miami Beach, Dade County.

Very similar abundances of the main heavy minerals were found by Miller (1945, p. 71) in nine samples of beach and dune sands from the Atlantic coast of Florida, but only three of the samples contained monazite (table 35). One of these three was dune sand.

TABLE 35.—*Mineralogical composition, in weight percent, of monazite-bearing concentrates from sand on the Atlantic coast of Florida*

[Modified from analyses by Miller (1945, p. 65-75). Symbol used: ------ absent]

	1	2	3
Corundum	Trace	Trace	2
Enstatite	1	3	2
Epidote	8	3	3
Garnet	4	8	2
Hornblende	Trace	------	------
Ilmenite	38	51	36
Kyanite	1	2	1
Magnetite	Trace	Trace	Trace
Monazite	Trace	Trace	Trace
Rutile	19	15	27
Sphene	Trace	------	Trace
Spinel	Trace	Trace	------
Staurolite	2	5	20
Tourmaline	Trace	1	Trace
Zircon	27	10	6

1. Beach south of St. Augustine, St. Johns County.
2. Beach at Matanzas Inlet, St. Johns County.
3. Vero Beach, Indian River County, rough concentrate from dune sand.

Evidently the enstatite reported by Miller was counted with hornblende in the other reports on the composition of concentrates from the Atlantic coast of Florida.

On the Atlantic coast of Florida the fraction of the natural black-sand concentrate having a specific gravity greater than 2.85 has the following percentages of heavy minerals (Martens, 1935, p. 1585):

	Weight percent
Amelia Island, Nassau County	24
Beach 2 miles south of Jacksonville Beach, Duval County	70
Beach 3 miles south of Mineral City, St. Johns County	6
South Beach, St. Augustine, St. Johns County	24
Daytona Beach, Volusia County	14
Melbourne Beach, Brevard County	86
Hollywood Beach, Dade County	28

In the natural concentrates the dominant minerals are ilmenite, zircon, and epidote (table 36).

The mineralogical composition of the beach sand and natural black sand at the coast is more complex than the inland sand at Trail Ridge. Epidote, garnet, and hornblende, which are less stable than minerals like ilmenite, rutile, zircon, and staurolite, are present on the beaches, locally in considerable abundance, but they are scarce to absent in the fossil placers along Trail Ridge. The unstable minerals are apparently lost by intrastratal solution in the old deposits, but are replenished along the shore by material transported in streams rising in the crystalline rocks of the Piedmont. The distribution of epidote, garnet, and hornblende is a regional feature. It was observed by Dryden (1958, p. 425) along the Atlantic coast of Georgia and the Carolinas.

TABLE 36.—*Mineralogical composition, in percent, of black sand from the Atlantic beaches of Florida*

[Modified from analyses by Martens (1928, p. 144). Symbol used: Ab, absent; P, present]

	1	2	3
Quartz and feldspar	52. 9	11. 9	2. 3
Ilmenite	25. 6	49. 6	50. 4
Zircon	11. 3	17. 2	14. 7
Rutile	2. 0	6. 6	18. 2
Monazite	1. 9	2. 1	. 1
Staurolite	1. 3	3. 0	8. 9
Epidote	1. 5	4. 8	. 1
Garnet	. 5	1. 2	5. 0
Kyanite	. 4	. 6	P
Sillimanite	. 7	. 9	. 06
Tourmaline	. 4	. 3	. 2
Hornblende	. 3	. 2	Ab
Leucoxene	. 4	. 6	. 1
Sphene	Ab	. 1	Ab
Spinel	P	P	. 06
Corundum	Ab	. 1	Ab
Collophane	. 6	. 9	Ab
Anatase	Ab	P	Ab
Shell (calcite)	P	P	Ab
Total	99. 8	100. 1	100. 1

1. Amelia Island, Nassau County.
2. Beach 3 miles north of Ponte of Vedra (Mineral City), St. Johns County.
3. Eau Gallie, Brevard County.

The persistence southward along the Atlantic coast of Florida of unstable minerals like epidote and garnet, which are not present in the older sedimentary rocks of the State and therefore must have been moved down the coast from the mouths of rivers reaching the Piedmont, was interpreted by Martens (1935, p. 1588) as evidence for a prevailing southward transport of heavy minerals. The southward variation in the composition of concentrates from the beach sands, however, is far from regular. A very great but irregular southward decrease in the relative abundance of hornblende with concomitant increase in relative abundance of tourmaline, probably caused by extreme differences in stability between the two minerals, is the clearest evidence for southward transport.

At localities where pairs of samples of natural sand and natural heavy-mineral concentrates were collected, ilmenite, rutile, and zircon were found to be relatively more abundant, and sillimanite, hornblende, and tourmaline relatively less abundant in the natural concentrate (Martens, 1935, p. 1586).

Monazite from the Atlantic beaches of Florida was described by Martens (1928, p. 133) as pale-greenish-yellow fairly well rounded grains about 0.004 inch in average diameter. A few grains as large as 0.01 inch have been observed as far south as Olympia Beach in Martin County and Miami Beach in Dade County (Martens, 1935, p. 1578). The monazite tends to be a little smaller than the associated zircon and much rounder than associated quartz, rutile, zircon, epidote, and ilmenite.

Most of the reported occurrences of monazite on the Atlantic coast of Florida were listed in the three preceding tables. Very few details about any of them are given in the literature, and there are no data on the reserves of monazite. The monazite-bearing localities in these tables for which there are little or no other data are St. Augustine, South Beach, and Matanzas Inlet, St. Johns County; Flagler Beach, Flagler County; Daytona Beach, Volusia County; Cocoa Beach, Brevard County; Fort Pierce, St. Lucie County; Olympia Beach, Martin County; the locality 5 miles south of Jupiter, Riviera Beach, and Boca Raton, Palm Beach County; Hollywood Beach and Miami Beach, Dade County; Upper Matacumba Key, Monroe County. Several of these reported occurrences of monazite are in some of the most highly developed and valuable urban areas on the east coast of the United States. They are obviously not conventional placer ground.

The beach and dune sand of Amelia Island, Nassau County, just south of St. Marys entrance at the extreme northeast corner of the State, was said everywhere to show thin streaks and small amounts of monazite-bearing black sand (Martens, 1928, p. 141; 1935, p. 1566). Monazite has been found on Fernandina Beach on the island (Mines Mag., 1957). In 1957 it was reported that the Union Carbide Ore Co. was planning to dredge holdings on Amelia Island to recover ilmenite, rutile, zircon, and monazite (Mining World, 1957c).

Several monazite-bearing localities and the first ilmenite placer mine in Florida are on the 35-mile stretch of coast and coastal islands between the mouth of the St. Johns River near Mayport, Duval County, and the mouth of the North River near St. Augustine in St. Johns County (Liddell, 1917, p. 153; Teas, 1921, p. 376; Martens, 1928, p. 127–130; Jones, W. H., 1949b, p. 580). Monazite is found in sand 200 feet south of the mouth of the St. Johns River, at Manhattan Beach, at Jacksonville Beach, and at Atlantic Beach, Duval County (Martens, 1935, p. 1566; Liddell, 1917, p. 153). Heavy minerals observed in beach sand between the mouth of the St. Johns River and St. Augustine include ilmenite, zircon, rutile, monazite, staurolite, epidote, zoisite, garnet, kyanite, sillimanite, magnetite, tourmaline, hornblende, leucoxene, spinel, anatase, muscovite, biotite, and corundum (Martens, 1928, p. 130).

Mineral City, now known as Ponte Vedra, in St. Johns County about 4 miles south of Jacksonville Beach, is the site of the first placer mining in Florida, as previously mentioned. The coast at the former placer is a gently sloping beach about 520 feet wide at low tide (Liddell, 1917, p. 153–154; Martens, 1928, p. 127–130). Backing the beach are a line of dunes about 200 feet wide that reach a height of about 12 feet above high tide, and behind the dunes is a low area paralleling the coast. The mined part of the deposit was the dunes and a zone of heavy minerals about 70 feet wide along the ocean side of their base. Sand in the dune area contained enough heavy minerals to be minable to depths as great as 50 feet below mean high tide, but the streak in front of the dunes could only be worked to a maximum depth of about 17 feet, of which the lower half was lean. The richest part of the placer deposits was in the streak at the foot of the dunes where a zone 25–35 feet wide and 2–2½ feet thick immediately in front of the dunes contained 60 percent of heavy minerals. In general the mined parts of the placer contained about 20 percent of heavy minerals. Between 1916 when the placer was opened and 1929 when mining ceased, the workings were extended along this rich streak for distances from Mineral City of 3 miles to the north and 8 miles to the south.

In the early days of the operation the raw black sand consisted of, in order of abundance, quartz, ilmenite, zircon, epidote, rutile, staurolite, monazite, kyanite, spinel, garnet, corundum, tourmaline, pyroxene, amphibole, feldspar, xenotime, pyrochlore, and magnetite (Liddell, 1917, p. 154). Platinum was present in small amounts, but gold was absent. Wet-plant processing of the natural black sand recovered 75 percent of the heavy minerals and gave a concentrate composed of the following percentages (Martens, 1928, p. 137):

	Percent
Ilmenite	55
Zircon	20
Rutile	6
Monazite	2
Staurolite, epidote and other minerals	14
Quartz	3
Total	100

An estimate of the monazite reserves in the deposit was given by Liddell (1917, p. 154) as 33 million tons of raw sand with at least 0.015 percent of monazite, or about 5,000 tons of monazite. Virtually none of the monazite was recovered. An output in 1916–17 was suggested by the contemporary descriptions of Liddell, but the actual output then, if any, must have been very small, because the total United

States production in those years was less than 20 short tons annually, and that amount is attributed to North Carolina (Santmyers, 1930, p. 15). In 1925 the property was reported to have produced 1 short ton of monazite. After the operation ceased in 1929 the land was developed as a residential area, and the surface improvements are more valuable than the monazite that was left.

Monazite is present on Anastasia Island in St. Johns County (Calver, 1957, p. 25).

A narrow and discontinuous beach on the west side of the Indian River about 1½ miles north of Eau Gallie, Brevard County, contains concentrates rich in ilmenite and rutile (Martens, 1928, p. 142; 1935, p. 1584; Rock Products, 1929). Similar narrow discontinuous beaches adjacent to coquina bluffs elsewhere along the Indian River were also reported to have small, rich concentrations of heavy minerals.

On the Atlantic coast south of Melbourne, Brevard County, at points 9.8 and 10.4 miles from the east end of the Melbourne causeway (J. B. Mertie, Jr., oral commun., 1961) are the placers mined by the Riz Mineral Co. and the Florida Ore Processing Co., Inc., in the 1940's for titanium minerals, zircon, and monazite. In Indian River County beach and dune placers on the west side of U.S. Route 1 near Winter Beach and dunes immediately south of Vero Beach were mined for the same minerals by the Florida Minerals Co. The deposits at Vero Beach are worked out, but the Winter Beach was being mined in the late 1950's and early 1960's.

PRESENT BEACHES AND DELTAS OF THE GULF COAST

The sand on the present beaches of the gulf coast in northwestern Florida was described by Martens (1935, p. 1594) as having rounder grains and a smaller variety of heavy minerals than the coastal sand on any part of the Atlantic side of the State. Most heavy-mineral suites from the northwestern part of the gulf coast lack hornblende, epidote, and garnet. Where these minerals are present, heavy minerals are sparse. The less common heavy minerals—chloritoid, zoisite, sphene, and hypersthene—of the east coast sand are absent from gulf coast sand. Mineralogical analyses of the heavy fraction from seven samples of ordinary beach sand from the gulf coast of Florida are listed in table 37. The composition of natural black sand layers interbedded with the ordinary beach sand along the gulf coast of Florida is given in table 38. Kyanite is much more common and sillimanite is much less common in the gulf coast sand than in the Atlantic coast sand.

TABLE 37.—*Mineralogical composition, in percent, of concentrates from beach sand, gulf coast of Florida*

[Modified from analyses (samples 1–3, 7) by Martens (1935, p. 1593) and analyses (samples 4–6) by Miller (1945, p. 71, table 1). Samples 1–3 and 7 are given in weight percent; samples 4–6 given in frequency percent. Symbol used: --, absent]

	1	2	3	4	5	6	7
Corundum	--	--	Trace	--	--	--	--
Enstatite	1	Trace	1	--	--	--	5
Epidote	--	--	--	--	--	--	3
Garnet	--	--	Trace	--	--	--	5
Hornblende	--	--	Trace	--	--	--	Trace
Ilmenite	8	23	19	22	25	32	26
Kyanite	35	30	45	27	22	18	
Sillimanite	--	--	--	1	2	2	--
Monazite	Trace	Trace	Trace	.2	.2	.3	Trace
Rutile	5	7	9	10	8	10	22
Sphene	1	1	Trace	--	--	--	Trace
Spinel	--	Trace	Trace	--	--	--	Trace
Staurolite	40	34	22	14	15	11	14
Tourmaline	2	3	5	10	14	11	2
Zircon	9	2	Trace	13	10	11	15
Magnetite	Trace	Trace	Trace	--	--	--	--
Leucoxene	--	--	--	3	4	5	--

1. Beach at Pensacola Bay 14.2 miles west of Camp Navarre, Santa Rosa County.
2. East Bay, 6 miles south of Milton, Santa Rosa County.
3. Santa Rosa Island, Santa Rosa County.
4. South of Florosa, Santa Rosa Island, Santa Rosa County.
5. 2 miles east of Phillips Inlet, Bay County.
6. Beacon Beach, Bay County.
7. Tampa, Hillsboro County.

TABLE 38.—*Mineralogical composition, in frequency percent, of natural black sand from the gulf coast of Florida*

[Modified from analyses by Martens (1928, p. 144). Symbol used: --, absent]

	1	2	3	4
Quartz and feldspar	12.4	68.2	41.5	1.1
Ilmenite	38.0	17.7	6.8	16.5
Zircon	17.9	5.0	6.6	68.6
Rutile	9.2	2.4	1.0	6.6
Monazite	1.1	.5	.05	1.5
Staurolite	6.8	1.3	1.9	1.7
Epidote	--	.3	.6	.06
Garnet	.05	Trace	.9	1.6
Kyanite	10.9	3.7	1.0	.6
Sillimanite	.4	.2	.7	.03
Tourmaline	1.7	.6	.6	.03
Hornblende	--	.2	.05	--
Leucoxene	1.3	.1	.1	.2
Sphene	--	--	Trace	.2
Spinel	.5	.1	Trace	.1
Corundum	--	--	Trace	--
Andalusite	--	--	.1	--
Collophane	--	--	36.0	1.8
Shell (calcite)	.1	Trace	2.3	Trace
Total	100.3	100.3	100.2	100.6

1. Crooked Island, Bay County.
2. Cape San Blas, Gulf County.
3–4. Venice, Sarasota County.

The differences in mineralogical composition between gulf coast and Atlantic coast sands in Florida were attributed by Martens (1935, p. 1594) to a probable longer sedimentary history for the sand on the gulf coast. The probable longer history is indicated by the shapes of the grains of sand, which are rounder on the gulf coast than on the Atlantic coast, and by the absence from the gulf coast of common minerals such as hornblende, epidote, and garnet, which are widely present in the source rocks in the Piedmont. Martens postulated that the present beach sand of the gulf coast is derived mainly by wave erosion of the Pleistocene sand of the coast, which deposits were in turn reworked from the Pliocene Citronelle Formation. Destruction of the unstable detrital minerals was ascribed mainly to interstratal solution in the permeable Citronelle Formation. Addition of fresh hornblende, epidote, and other unstable heavy minerals to the beaches by streams was said to be prevented because only one stream, the Appalachicola River, presently reaches the metamorphic rocks in the Piedmont, and its outlet is a delta in a bay, and apparently little of the present load reaches the outer beaches from the delta and bay (Tanner and others, 1961, p. 1080).

The unusual abundance of kyanite in heavy-mineral suites from beaches in northwestern Florida and the sparseness of sillimanite is here interpreted to indicate that the ultimate source of the heavy minerals on this coast was the crystalline rocks of western Georgia and eastern Alabama. Notable amounts of kyanite are a distinguishing feature of heavy-mineral concentrates from streams in Harris County, Ga. (Espenshade and Potter, 1960, p. 103), and from the main stem of the Chattahoochee River in Georgia (Cazeau and Lund, 1959, p. 53). Sillimanite is much less common in this region than it is in the Piedmont of North and South Carolina.

Monazite grains from the gulf coast are small and well rounded (Miller, 1945, p. 69). They are colorless to pale yellowish brown or greenish brown. Most of the monazite-bearing localities that have been mentioned in the literature are listed in the two preceding tables. The occurrences at Pensacola Bay, East Bay, and Santa Rosa Island in Santa Rosa County have not been described in detail, although in the 1940's the area was apparently sampled by the U.S. Bureau of Mines (Miller, 1945, p. 68). On the north side of Santa Rosa Island opposite Camp Walton, thin narrow strips of heavy minerals are found along the shore (Martens, 1928, p. 147), and it may be that this is the kind of material that was sampled. No additional information is available on the monazite-bearing sand in the Tampa area, Hillsboro County.

Layers of heavy minerals, possibly as much as several feet thick, form dark hard partings in interbedded quartz sand cemented by carbonized organic debris exposed at the base of bluffs which rise about 20 feet above Chotawhatchee Bay near Haseman, Walton County (Haseman, 1921, p. 75–77). About 80–90 percent of the deposit is sand mixed with some 5–20 percent of organic debris and small amounts of clay. Where the organic debris is wet it is black and solid, but where it is dry it is brown and friable. The vegetal layers extend into the water of Chotawhatchee Bay. On its landward side the deposit is surrounded by large fresh-water lakes and swamps. The layers of heavy minerals were reported to contain ilmenite, rutile, zircon, and monazite, but the abundance of the minerals is not described. The association of heavy minerals with carbonized organic debris resembles the placers at Trail Ridge, but the age of the organic debris at Chotawhatchee Bay is not known. Haseman (1921, p. 76–77) inferred that the deposit might have formed after the area was settled by Europeans, because a part of a mast in which a lag screw and square iron nail were set was dug up about 60 feet from the edge of the bluff and 8 feet below sea level. The location of the mast would place it in the organic layer, but the fact that the vegetal matter in the layer is carbonized and the mast was not would seem to preclude contemporaneity.

Dark minerals locally form thin coatings over the white sand of Inlet Beach on the gulf shore for distances of 2 miles to the east and 5 miles to the west of Phillips Inlet, Bay County and Walton County (Martens, 1928, p. 147). These coatings are impermanent, changing with every storm, and are formed by the wind drying the surface sand and sweeping the light grains away. At the back of the beach a more permanent deposit is found. It consists of alternate dark layers of heavy minerals and light layers of quartz sand. Monazite is present, and staurolite and kyanite are more common at Inlet Beach than farther east around Crooked Island and Cape San Blas. Beach sand in a zone from 16 to 40 miles west of Panama City, Bay County, was explored for heavy minerals including monazite in the 1950's (J. B. Mertie, Jr., oral commun., 1961; Lenhart, 1956, p. 69).

Thin layers of heavy minerals containing monazite have been described on the shoreward side of Crooked Island along St. Andrews Sound, Bay County (Martens, 1928, p. 145). These small deposits lie between the low tide and high tide lines and are evidently formed by the sorting action of small waves because the locality is sheltered from storms. On the gulf side of Crooked Island, thin layers of heavy minerals are also found, but thicker layers are also present. The layers are most common on the upper beach near the foot of dunes and apparently were deposited during storms. Staurolite and kyanite are particularly common in the heavy sand on Crooked Island. None of the deposits was thought by Martens to be large enough to mine.

Thin layers of heavy minerals extend northward for some miles along the back of the gulf beach near the fronts of dunes between Cape San Blas to St. Joseph Point, Gulf County (Martens, 1928, p. 145). The concentrates are present only along the part of the beach reached by storm waves or very high tides. They are neither wide enough nor thick enough for mining.

The distribution of heavy minerals in the vicinity of Cape St. George and the mouth of the Appalachicola River, Franklin County, was investigated by Tanner, Mullins, and Bates (1961, p. 1082–1086), who found that the Appalachicola River seems to be delivering a larger quantity of heavy minerals to its mouth than is accounted for by the amount of heavy minerals on adjacent modern beaches and barrier islands. Alongshore currents and wave energy at the mouth of the river seem to be inadequate to counteract the transporting capacity of the river current. Large shoals have been built up off the present mouth of the Appalachicola and at positions in the Gulf of Mexico off Cape St. George and Cape San Blas. The large shoals seem to mark former positions of the river mouth. The degree of sorting of the sand and the location of the heavy minerals in the vertical profile of the shoals were interpreted by Tanner, Mullins, and Bates (1961, p. 1086) to show that the sand on the shoals has not been normally winnowed. It seems to have been rearranged locally by storm waves. When the reworked sand settled after storms, the heavy minerals and coarse-grained quartz were deposited first, settled near the base of the redeposited sand, and were covered by fine sand containing scant heavy minerals. Surface samples of sand from the shoals and other parts of the delta area disclose low average abundances of heavy minerals (Tanner and others, 1961, p. 1083–1084). Two groups of samples from the shoal at Cape St. George averaged about 0.45 percent of heavy minerals: the average of 38 samples was 0.48 percent and that of 77 samples was 0.43 percent. Seventeen samples from the shoal east of St. George Island averaged 0.15 percent of heavy minerals. In St. George Sound the heavy minerals in bottom sediments reached a maximum of 0.55 percent near the mouth of the river and decreased eastward. One sample from the bottom of the Gulf of Mexico just west of the northwest end of St. George Island contained 0.8 percent of heavy minerals. The richest samples contained only 1–1.5 percent of heavy minerals and came from the Cape St. George area.

The average composition of the heavy-mineral fraction from samples of sand from the surface of the shoal near Cape St. George was reported by Tanner, Mullins, and Bates (1961, p. 1082–1083) as follows:

	Percent	
	A	*B*
Ilmenite, magnetite	33. 0	39. 7
Epidote	12. 1	7. 7
Kyanite	12. 0	11. 7
Staurolite	6. 5	8. 3
Sillimanite	6. 4	(1)
Hornblende	5. 8	4. 0
Leucoxene	5. 7	(2)
Rutile	5. 7	6. 7
Zircon	4. 9	5. 7
Tourmaline	4. 1	5. 4
Garnet	1. 3	(1)
Monazite	1. 3	5. 3
Other minerals	1. 2	5. 5

[1] In other minerals.
[2] Included with ilmenite.

A. Average of 38 samples.
B. Average of 10 samples which had a mean tenor of 1.2 percent of heavy minerals.

At depths of 12–15 feet below the tops of the shoals the sand may contain 4 percent or more of heavy minerals if the sand was actually reworked as inferred. The central shoal off Cape St. George may contain as much as 20 million short tons of heavy minerals among which there may be 2.5 million short tons of monazite (Tanner and others, 1961, p. 1086).

Large amounts of monazite-bearing locally zircon-rich black sand have been reported to occur on the gulf beach at Venice, Sarasota County (Martens, 1928, p. 143; J. B. Mertie, Jr., oral commun., 1961). The heavy minerals are especially conspicuous in an area extending southward about 2 miles from Casey Pass, and the main concentrations occur between the beach ridge and the high tide line.

GEORGIA

Monazite seems to have been discovered in the 1880's in some of the placer gold workings in northeastern Georgia (Eng. and Mining Jour., 1888, p. 2), but it was not mined in the State, even at the height of the industry in the Carolinas in the late 1800's and early 1900's (Santmyers, 1930, p. 15). For the most part the Georgia gold placers do not contain monazite. It is most commonly found as a minor accessory mineral in crystalline rocks in the central part of the Piedmont, in stream sediments on crystalline rocks, in the unconsolidated sediments of the Coastal Plain and in the beds of streams flowing therein, and on the beaches of the Sea Islands along the Atlantic coast. Probably the best potential economic sources of monazite in the State are on the Sea Islands, in Coastal Plain sediments in the extreme southeastern part of the State, and locally along the inner edge of the Coastal Plain.

CRYSTALLINE ROCKS

The principal areas of monazite-bearing crystalline rocks in Georgia were defined by Mertie (1953, pl. 1; 1957, p. 1767) as occupying two belts, one in the central Piedmont and the other in the Blue Ridge. In the central Piedmont the belt extends southwestward from Hart County and Elbert County, at the border with South Carolina, to Troup County at the Alabama line as part of a much longer belt of monazite-bearing crystalline rocks observed by Mertie from Alabama to Virginia. Throughout the belt the monazite occurs in granitic rocks, pegmatite, granitic gneiss, migmatite, and middle and upper amphibolite facies schists and gneisses of original sedimentary origin. Not all the rocks in the belt, however, are monazite bearing. The belt in the Blue Ridge and adjacent areas was observed by Mertie in Rabun and Hall Counties in the extreme northeastern part of Georgia and has been observed as a discontinuous trace in parts of North Carolina and Virginia. The monazite-bearing rocks in the Blue Ridge belt of Mertie are plutonic gneisses, schists, granite, and pegmatite.

Mertie (1953, p. 22–23) reported that granite gneiss, schist, and pegmatite exposed at four localities near Bowersville, Hart County, in the main belt are monazite bearing. Elsewhere in Hart County exposures discovered by Mertie to be monazite bearing include gneissic pegmatite and granite south of Hartwell and granite southeast of Royston (Mertie, 1953, p. 22–23). Monazite was reported as scarce in the crystalline rocks, principally biotite schist and sillimanite schist (Grant, 1958, pl. 1), and very scarce in the commercial muscovite pegmatite dikes of the Hartwell district, Hart County (Jahns and others, 1952, p. 31).

In Elbert County a monazite-bearing dike of granite is exposed 2.5 miles southwest of Dewy Rose (Mertie, 1953, p. 23).

Accessory monazite was reported from granitic gneiss near Danielsville, granite near Carlton, and gneiss near Colbert in Madison County, and pegmatite near the line between Madison and Clarke Counties (Mertie, 1953, p. 22–23).

Granite from the west side of the Liberty quarry northeast of Lexington, Oglethorpe County, was shown to contain accessory monazite. Granite gneiss in the county is also monazite bearing (Mertie, 1953, p. 22).

Monazite was found in 1949 and 1952 by Mertie (1953, p. 21–22) in granite near Athens, Barber Creek, and Princeton, Clarke County. In 1953 Parizek (1953, p. 24–25) described a body of monazite-bearing granite intrusive into garnetiferous biotite schist and migmatite in Clarke County. The granite is massive, medium to coarse grained, and locally porphyritic. It consists principally of quartz, perthite, orthoclase, sodic plagioclase, muscovite, and biotite with accessory zircon, monazite, tourmaline, rutile, and magnetite. Numerous coarsely crystalline pegmatite dikes, sheets, and vein networks composed of orthoclase, albite, quartz, and muscovite occur in the schist adjacent to the granite. Gneissoid biotite granite intrusive into sillimanite schist in the Athens area, Clarke County, has dominant accessory xenotime, monazite, and zircon, with subordinate accessory hornblende, epidote, staurolite, garnet, magnetite, and sillimanite (Hurst, 1953, p. 246–249). Near the contacts between the granite and the wallrocks, the relative abundance of xenotime, monazite, and zircon declined and that of epidote and sillimanite increased. Garnetiferous sillimanite-bearing staurolite schist and garnetiferous staurolite-bearing sillimanite schists in the metamorphic aureole around the granite at Athens contain small amounts of accessory monazite and xenotime, but monazite was not reported from sillimanite-free schists.

Banded gneiss northeast of Monroe, Walton County, and granite and migmatite in the vicinity of Covington, Newton County, contain accessory monazite (Mertie, 1953, p. 20–22).

In Spalding County monazite-bearing granite has been found near Zetella, and in Meriwether County granite and granite gneiss near Greenville, the Snelson Granite near Harris, Durand, and Warm Springs, banded granite gneiss near Gay, and mica gneiss near Woodbury were shown to contain monazite (Mertie, 1953, p. 20–22).

Four samples of granite, three samples of granite gneiss, and a sample of gneiss from the La Grange area, and one sample of granite gneiss from a locality near West Point, Troup County, were reported to be monazite bearing (Mertie, 1953, p. 21–22).

Monazite is present as an accessory mineral in a granite stringer in augen gneiss from a point just east of a mica mine 3½ miles northwest of Yatesville, Upson County, in the Thomaston-Barnesville pegmatite district (Mertie, 1953, p. 21). Monazite was reported to be very scarce in the gneisses and schists of the Thomaston-Barnesville district and to be absent from the commercial muscovite pegmatite dikes of the district (Jahns and others, 1952, p. 31; Heinrich and others, 1953, p. 331), but at the Colbert mine about 9 miles northeast of Thomaston, monazite has been found in mica pegmatite (J. B. Mertie, Jr., oral commun., 1961).

Pegmatite in northwestern Crawford County contains minor accessory monazite (Fortson and Navarre, 1959, p. 1309).

Two samples of granitic gneiss from the vicinity of Franklin and one from Texas, Heard County, were found by Mertie (1953, p. 21) to contain monazite; massive granite exposed west of Sharpsburg, Coweta County, is monazite bearing. Concentrates from granite exposed at Stone Mountain, De Kalb County, contain the following percentages of heavy minerals:

[Analyst: Hurst (1953, p. 259)]

	Percent		Percent
Monazite and zenotime	5	Hornblende	2
Epidote	5	Apatite	1
Muscovite	5	Tourmaline	35
Magnetite	3	Garnet	40
Zircon	2		
Sillimanite	2	Total	100

Granite and pegmatite exposed near Clermont, Hall County, in the Blue Ridge monazite belt of Mertie contains accessory monazite (Mertie, 1953, p. 21–22).

STREAM SEDIMENTS IN THE PIEDMONT AND BLUE RIDGE PROVINCES

Monazite is present in varying quantities in the unconsolidated sediments in the valleys of streams rising in the two monazite belts in Georgia, and it persists downstream beyond the limits of the belts. The largest number of monazite-bearing streams in the Piedmont and Blue Ridge physiographic provinces are in the central Piedmont belt. Investigations of monazite deposits in sediments in the present valleys of the Oconee River, Flint River, and Chattahoochee River were made by the U.S. Geological Survey in 1952. The results of these investigations, summarized in the following paragraphs, showed that detrital monazite progressively decreased in abundance southwestward along the belt and that deposits in tributaries to the Chattahoochee River are leaner in monazite than deposits in tributaries to the Oconee River. This southwestward decrease in abundance of detrital monazite in the stream seems to be related to a decrease in the amount of monazite in the bedrock, which is paralleled by a decrease in regional metamorphism from sillimanite-almandine and staurolite-kyanite subfacies in the basin of the Oconee River to staurolite-kyanite subfacies in the basin of the Chattahoochee.

The fluviatile monazite placers in an area of 310 square miles in the drainage basin of the Oconee River in parts of Oconee, Barrow, Clarke, Jackson, and Oglethorpe Counties were examined by P. K. Theobald, Jr., and J. W. Whitlow of the U.S. Geological Survey in 1952 (P. K. Theobald, Jr., written commun., 1954). The streams examined included Marburg Creek, tributary to the Apalachee River in Barrow County; Sandy Creek, Falling Creek, and Barrow Creek which join the Oconee River in Oglethorpe County; Rose Creek, Wildcat Creek, and Porters Creek, which enter the Oconee River in Oconee County; Butler Creek, Barber Creek, and McNutt Creek, tributaries to the Middle Oconee River in Oconee County; Bear Creek and other streams entering the Middle Oconee River in Clarke County; Beech Creek, which flows into the Middle Oconee River in Barrow County; and Barbers Creek, Cedar Creek, and Hawk Creek, tributary to the Mulberry River in Barrow County. Most of the area in Barrow and Oglethorpe Counties drained by these streams is underlain by a migmatite complex of biotite schist and sillimanite schist invaded by granite. Parts of the area in Clarke and Oconee Counties are underlain by a large body of granite having migmatitic wall zones.

The investigated parts of these counties can be divided on a basis of detrital heavy minerals into three major mineralogic provinces: a magnetite-rich zircon-bearing province associated with granite and gneiss in Barrow County, a monazite-rich province in Oconee County and Clarke County, and a magnetite-rich province associated with granite in Oglethorpe County. Small amounts of monazite and epidote are present in the two magnetite-rich suites. The greatest variety of heavy minerals is in the monazite-rich province which is associated with high-rank metamorphic rocks, the migmatite complex, and granite. The minerals include ilmenite, magnetite, rutile, garnet, zircon, monazite, sillimanite, amphibole, and epidote.

Many of the streams are entrenched in their lower reaches and have broad flood plains as much as 2000 feet wide in their middle and upper reaches. The average thickness of alluvium in the flood plains is about 12 feet and the greatest thickness of alluvium is about 20 feet. Clayey sediments are commonly near the top of the sequence of alluvium. The sequence grades downward from clay to sand and silt with local thin layers of gravel overlying weathered crystalline rocks. The average composition of the sequence of flood-plain sediments is 3 percent of gravel, 41 percent of sand, 24 percent of silt, and 32 percent of clay. Because of the low proportion of gravel, the flood-plain sediments are unfavorable for monazite placers.

Monazite was present in 93 percent of 55 samples of gravel and 69 percent of 41 samples of sand and other materials taken in the drainage basin of the Oconee River. The average tenor of the samples of gravel was 2.1 pounds of monazite per cubic yard, and of the samples of sand, silt, and clay about 0.7 pound of monazite per cubic yard. The highest tenors in monazite were observed in three areas underlain by the migmatite complex: at the heads of McNutt and Bear Creeks, lower Barber Creek and the head of Butler Creek, and on central Rose Creek, the head of Wildcat Creek, and lower Porters Creek. These high-tenor areas seem to have monazite placers that are suitable for small-scale mining. The large flood plains, except those on the Middle Oconee River and Barber Creek, are developed on biotite schist that is a poor source for monazite; hence, they are not economic placers. Large flood plains on parts of the Middle Oconee River and Barber Creek may contain as much as 0.7–1 pound of monazite per cubic yard of alluvium.

Stream sediments in the valleys of eastern tributaries to the Flint River in an area of 210 square miles in parts of Spalding County and Pike County were examined for monazite in 1952 by D. W. Caldwell (written commun., 1954) of the U.S. Geological Survey. From north to south the streams studied are Heads Creek, Shoal Creek, Wildcat Creek, and Flat Creek in Spalding County, and Honey Bee Creek, Birch Creek, and Elkins Creek in Pike County. These streams are underlain by biotite gneiss, biotite schist, and biotite granite. About 5 miles south of the mouth of Elkins Creek, the Flint River flows across quartzite which, because of its resistance to erosion, has formed a local base level to which the Flint River is graded. Upstream from the quartzite many of the tributaries to the Flint River have low gradients and are swampy to their sources. The flood plains are commonly narrow and discontinuous, between 100 and 1,100 feet wide and a few hundred yards to 2 miles long. Alluvium in the flood plains ranges in thickness from 7 to 20 feet and averages 13 feet. It consists of a thin sheet of unconsolidated quartz-pebble gravel or pebbly sand resting on weathered bedrock and overlain by coarse sand, clayey fine sand, and clay. Only about 1 percent of the sediment in these valleys is gravel; 36 percent is clay.

Monazite makes up 1 percent or more of the heavy-mineral concentrates from the southern headwater tributaries to Shoal Creek east of Griffin, Spalding County, southward to the upper parts of Elkins Creek southwest of Zebulon, Pike County. In Heads Creek and the lower part of Elkins Creek, monazite is present as less than 1 percent of the concentrate. Locally the concentrates contain as much as 20 percent of monazite, but in most areas they contain less than 10 percent of monazite. Typical monazite-bearing concentrates from this area consist mainly of ilmenite with some magnetite and rutile and a few percent of monazite. Small amounts of zircon, garnet, kyanite, magnetite, tourmaline, spinel, and epidote are variably present.

Detrital monazite from a tributary to the Flint River in Spalding County, collected by J. B. Mertie, Jr., and analyzed by F. C. Grimaldi of the U.S. Geological Survey, was reported to contain 4.42 percent of ThO_2 and 0.26 percent of U_3O_8 (Mertie, 1953, p. 12). The small amount of gravel in the streams in Spalding and Pike Counties has a tenor in monazite that ranges from 0.6 to 6 pounds of monazite per cubic yard, but the other fluvial sediments contain less than 0.5 pound of monazite per cubic yard. None of these streams seems to be a commercial source for monazite.

Fluvial sediments in the valleys of eastern tributaries to the Chattahoochee River in an area of 660 square miles in Troup County, western Meriwether County, and northern Harris County, Ga., were sampled for detrital monazite in 1952 by D. W. Caldwell (written commun., 1954) of the U.S. Geological Survey. Streams examined include Yellowjacket Creek, Flat Creek, Beach Creek, and Flat Shoals Creek in Troup and Meriwether Counties; Wilson Creek, Maple Creek, and Long Cane Creek in Troup County; Sulfur Creek in Meriwether County, and House Creek, Mountain Creek, and Palmetto Creek in Harris County. Monazite is absent from Wilson and Maple Creeks, sparingly present in a small proportion of the concentrates from Yellowjacket Creek, Flat Creek, and Long Cane Creek, and present in low tenors in most concentrates from the other streams. Flat Shoals Creek has the most monazite of any of the streams, but even it seems to have no possibilities as an economic source of placer monazite.

The crystalline rocks in the drainage basins of these streams consist of gneisses and schists of high metamorphic grade and some granite in Troup, Meriwether, and northern Harris Counties; they are separated by a north-northeast-trending fault near Mountain Creek, Harris County, from the Pine Mountain Series of medium to low-grade metasedimentary rocks south of the fault (Hewett and Crickmay, 1937, p. 31; Stose and Smith, 1939). The main monazite-bearing streams flow on biotite gneiss, biotite schist, injection gneiss, and granite in the southeastern part of Troup County, southwestern Meriwether County, and the extreme northern part of Harris County north of the fault. In the northern two-thirds of Troup County and northwestern Meriwether County, streams with little or no monazite flow mainly on the Snelson Granite. A very little monazite has been found in streams south of the fault in Harris County. These minor occurrences of monazite may be recycled detrital material from little patches of Tertiary(?) sedimentary rocks in terraces on Pine Mountain.

Flood plains along the large streams between Pine Mountain and the northern part of Troup County characteristically range greatly in width along their middle and lower reaches and are of uniform width in the upper reaches. The flood plains of small tributaries to the Chattohoochee River widen downstream. Widths of 500–1,500 feet are common in the upstream parts of the large creeks, whereas the lower ends of the flood plains are only 150–350 feet wide. The thickness of the flood-plain deposits is commonly 10–18 feet, in a few places 20 feet, and averages 12.6 feet. The fluvial deposits form a sequence that grades downward from silt and clay at the top of the flood plain to coarse sand and gravelly sand overlying weathered bedrock. Relative abundance of the components of the sequence are 4 percent of gravel, 47 percent of sand, 15 percent of silt, and 34 percent of clay.

Heavy-mineral concentrates from the tributaries to the Chattahoochee form three distinct suites which are related to the source rocks. A suite in which monazite, zircon, and rutile are common, ilmenite is abundant, and magnetite is very variable in occurrence comes from streams which flow on the granite and high-grade gneiss, schist, and injection gneiss in the southeastern part of Troup County, southwestern Meriwether County, and the extreme northern part of Harris County. A suite in which monazite is scarce, magnetite is abundant, and ilmenite, epidote, and amphibole are common comes from streams draining areas underlain chiefly by Snelson Granite in Troup County. A suite in which monazite is absent or scarce, magnetite is scarce, epidote and amphibole are absent, ilmenite is common, and kyanite is abundant comes from streams that flow over rocks of the Pine Mountain Series in Harris County. Several other heavy minerals are sporadically present in one of the suites and scarce in or absent from the other suites. These minerals include xenotime, spinel, tourmaline, garnet, sillimanite, and staurolite. The variation in their occurrence also conforms to the source rocks and fits the three suites defined by the main heavy minerals.

Concentrates from areas of gneiss and migmatite where there is the most monazite contain only 1–12 percent of monazite. These concentrates in only a few places contain more than 6 percent of monazite, and the tenors of the most favorable fluvial sediments are generally 0.1–0.5 pound of monazite per cubic yard. These tenors are too low for economic recovery of the monazite in the eastern tributaries to the Chattahoochee River in Georgia.

Heavy sand from Dukes Creek and from the Chattahoochee River about 4 miles below the mouth of Dukes Creek in White County was said to contain minor amounts of monazite and dominant garnet (Zodac, 1953, p. 57). Small quantities of magnetite, rutile, and zircon were present in the concentrates from both localities, and staurolite was a minor component of the sample from the Chattahoochee River. Monazite was observed in black sand from gold placers at the Glade mine and elsewhere in stream sand in the vicinity of The Glades, Hall County (Eng. and Mining Jour., 1888, p. 2; Teas, 1921, p. 6). The Glades, according to Mertie (1953, p. 26), is an abandoned townsite, formerly the center of a gold placer camp. In extreme northeastern Georgia, detrital monazite occurs with placer gold in Rabun County (Dennis, 1898, p. 487; Pratt, 1907b, p. 109; Sterrett, 1907a, p. 109; Teague and Furcron, 1948). Concentrates from the placer were estimated by D. B. Sterrett to contain about 40 percent of monazite, and the monazite was said to have 4 percent of ThO_2 (Pratt, 1916, p. 40). Apparently the deposit was never mined for monazite because there is no record of monazite having been produced in Georgia. The localities at The Glades, Dukes Creek, and Rabun County are in part of the Blue Ridge belt of monazite-bearing crystalline rocks defined by Mertie (1957, p. 1767).

UNCONSOLIDATED SEDIMENTS OF THE COASTAL PLAIN PROVINCE

Unconsolidated sediments of Cretaceous and Tertiary age at the inner edge of the Atlantic Coastal Plain physiographic province in Georgia consist largely of debris derived from the crystalline rocks of the Piedmont and Blue Ridge. The main units of these sediments in which detrital monazite has been found are the Tuscaloosa Formation of Cretaceous age and the McBean and Barnwell Formation of Eocene age (Dryden, 1958, p. 393). Terrace deposits of Tertiary (?) age are found at high places on the Piedmont as far as 20 miles inland from the present west edge of the Coastal Plain. Gravel from one of two sampled terraces on Pine Mountain, Harris County, contains monazite (D. W. Caldwell, written commun., 1954). Unconsolidated sediments of late Pleistocene to Recent age in the eastern part of the State, especially sand on the Pamlico terrace and Silver Bluff terrace, have been reported to contain monazite (Neiheisel, 1962, p. 368).

The abundance of monazite in 40 samples of sand from the Tuscaloosa Formation, 11 from the McBean Formation, and 22 from the Barnwell Formation, in the western part of the Coastal Plain in Georgia, was estimated from the radioactivity of concentrates by Dryden (1958, p. 394, 407–409). For these estimates it was assumed that monazite was the dominant source of radioactivity. Inferred tenors of the natural sand were calculated from the estimated abundance of monazite in the concentrate. The results of the investigation showed that 15 samples (37 percent) from the Tuscaloosa Formation, 4 samples (36 percent) from the McBean Formation, and 1 sample (4 percent) from the Barnwell contained more than 0.25 pound of monazite per cubic yard of sediment. Coarse sand and gravelly sand at the base of the Tuscaloosa Formation contained the most monazite, about 2 pounds per cubic yard, of any of the unconsolidated rocks.

Mineralogical study of the samples revealed that all the concentrates contain about the same suite of heavy minerals (Dryden, 1958, p. 393–394, 425). At least half of the concentrate is commonly ilmenite and leucoxene, and the rest is made up of highly variable percentages of other minerals, which in approximate order of abundance are zircon, rutile, monazite, staurolite, kyanite, sillimanite, tourmaline, and spinel. Unstable minerals such as garnet, epidote, and hornblende are not present. To concentrates lacking unstable minerals, Dryden gave the name restricted suite. He found that the restricted suite was characteristic of the unconsolidated sediments of the Coastal Plain that are older than late Pleistocene. Upper Pleistocene and Recent unconsolidated sediments contain both unstable and stable heavy minerals.

Sand from the Tuscaloosa and Barnwell Formations exposed west of Augusta in Richmond County, from these formations plus the McBean in McDuffie, Warren, Glascock, and Jefferson Counties, and from the McBean and Barnwell Formations around Waynesboro in Burke County was observed by Dryden (1958, p. 422) to be somewhat leaner in monazite than that from the same units elsewhere in Georgia. Only 2 out of 31 samples contained more than an estimated quarter of a pound of monazite per cubic yard of sediment. In part of these same areas, however, particularly around Thomson, McDuffie County, some highly radioactive zones have been detected by airborne radioactivity survey (Schmidt, 1961). Some of the Coastal Plain sedimentary rocks around Thomson were shown by Mertie (1953, p. 13, pl. 1) to contain more than usual amounts of monazite. The results of the airborne survey indicate that samples might be selected in the Thomson area that would be considerably richer in monazite than 0.25 pound per cubic yard.

Three out of five samples of sand from the Tuscaloosa Formation and two out of three samples from the McBean Formation exposed around Sandersville, Washington County, were estimated by Dryden (1958, p. 407–408) to contain more than 0.25 pound of monazite per cubic yard. Sand from the Barnwell Formation, sampled at seven places in the Sandersville area, had less than a quarter of a pound of monazite per cubic yard.

The Tuscaloosa and Barnwell Formations exposed in areas west and southwest of Milledgeville, Baldwin County, including parts of Jones and Wilkinson Counties, were found by Dryden (1958, p. 407–408) to be lean in monazite.

Small amounts of monazite were reported by Dryden (1958, p. 407–408) to be present in sand from the Tuscaloosa and Barnwell Formations exposed in parts of Bibb, Twiggs, and Jones Counties at and north of Dry Branch, Bibb County. A microscopic examination by B. F. Laney of the U.S. Geological Survey of a sample of clay from a pit near Dry Branch was reported to have disclosed a very large variety of extremely fine-grained accessory minerals including quartz, feldspar, wad, limonite, muscovite, magnetite, hematite, ilmenite, zircon, rutile, apatite, tourmaline, corundum, and monazite (Sproat, 1916, p. 14). Most of these grains passed through a 260-mesh sieve, and some were much finer. The size and species of the heavy minerals indicates that this is a restricted suite of detrital grains like that noted by Dryden (1958, p. 425) in the Tuscaloosa, McBean, and Barnwell Formations and that the minerals were deposited with the clay in a sedimentary environment. Several clay deposits in the Dry Branch area are bleaching clays or fuller's earth (Lang and others, 1940, p. 19–20, 263–268) and may be bentonitic. There seems to be scant possibility, however, that the monazite in this clay is of pyroclastic origin because the clay is interbedded with sand that contains detrital monazite.

The Tuscaloosa and Barnwell Formations outcropping in Bibb and Peach Counties southwest of Macon and the Tuscaloosa Formation between Knoxville, Crawford County, and Butler, Taylor County, are lean in monazite (Dryden, 1958, p. 407–408). In parts of Talbot, Marion, Chattahoochee, and Muscogee Counties east of Columbus, Ga., four out of nine samples of sand from the Tuscaloosa Formation were estimated by Dryden (1958, p. 407–408) to contain more than 0.25 pound of monazite per cubic yard. At a locality near Coleman, Randolph County, a sample of sand from the McBean Formation contained an estimated 0.25 pound of monazite per cubic yard (Dryden, 1958, p. 407–408).

The heavy minerals in eight samples of sand of late Pleistocene age and nine samples of sand of Recent age exposed on marine terraces along the southeast edge of the Coastal Plain in Georgia were studied by Neiheisel (1962, p. 368–374). He found that all the samples contain monazite, but that, relative to Recent sand, the Pleistocene sand tends to be impoverished in total unstable minerals. This observation is in agreement with earlier statements by Dryden (1958, p. 393–394). The average composition of these heavy-mineral suites is shown in table 39, where it can be seen that epidote

TABLE 39.—*Mineralogical composition of heavy-mineral fraction of 17 samples of sand from marine terraces in southeastern Georgia*

[Modified from analyses by Neiheisel (1962, p. 368, table 1)]

	Pamlico terrace	*Silver Bluff terrace*
Total heavy minerals (avg percentage of raw sand):		
Range	0. 4–2. 5	1. 1–2. 3
Average	1. 2	1. 7
Individual heavy minerals (avg percentage of heavy-mineral concentrate):		
Hornblende	. 5	. 2
Epidote	1. 1	6. 0
Sillimanite	13. 6	14. 7
Ilmenite	43. 9	45. 3
Leucoxene	3. 5	2. 9
Rutile	10. 1	6. 8
Zircon	15. 6	12. 8
Monazite	1. 2	1. 6

is much less abundant in sand from the Pamlico terrace, which was formed in middle Wisconsin time, than it is in sand from the younger and lower Silver Bluff terrace. The monazite-bearing samples of sand came from exposures in parts of Liberty and Bryan Counties, in McIntosh County and eastern Long County, and in southern Glynn County and northern Camden County.

Monazite was observed by Mertie (1953, p. 14) in six of eight samples from unconsolidated sediments of Pleistocene age in the Nahunta area, Brantly County, in one out of two samples from the Racepond area, Charlton County, and in three samples from the Jerusalem area in Charlton and Camden Counties. Anomalously high radioactivity attributable to concentrations of monazite and other heavy minerals in the surface sand was observed in five areas in the Folkston area, Charlton County by Moxham (1954b). Three localities northeast of Folkston were thought to be concentrations formed on old shorelines during the retreat of the Wicomico sea in Pleistocene time. To the south of Folkston, however, the anomalously radioactive concentrations of heavy minerals may have been deposited by the St. Marys River.

Layers of black sand were reported to be associated with tarry to pulverulent brown to black carbonized organic debris at a locality 3 miles west of St. George Charlton County (Teas, 1921, p. 377). The black sand was said to resemble, in mineralogical composition, the monazite-bearing ilmenite sands of the sea islands along the coast of Georgia. A resemblance to the Trail Ridge deposits in northeastern Florida is suggested by the association of heavy minerals with carbonized organic debris.

STREAM SEDIMENTS IN THE COASTAL PLAIN PROVINCE

Sediments from streams that head in the Coastal Plain were found by Dryden (1958, p. 425) to be leaner in total heavy minerals but richer in monazite than sediments from streams that enter the Coastal Plain from the Piedmont; however, no examples were given for streams in Georgia. It is probable that some streams entirely within the extreme western part of the Coastal Plain, particularly in the area from Augusta westward to McDuffie County, are richer in monazite than streams in the monazite belt in the Piedmont. A placer with gravel containing 1.5 pounds of monazite per cubic yard was discovered in this part of the western Coastal Plain in 1951 by Mertie (1958, p. 13). He reported the deposit to be in a small tributary to Sweetwater Creek about 3 miles east of Thomson, McDuffie County.

Six samples of sand from rivers that rise in the Piedmont and cross the Coastal Plain in central Georgia were reported by Neiheisel (1962, p. 368) to contain from 0.5 to 2.4 percent of heavy minerals, monazite making up about 1 percent of the concentrate, that is, about 0.005–0.02 percent of the raw sand:

	Percent
Total heavy minerals (avg percentage of raw sand):	
Range	0. 5–2. 4
Average	1. 3
Individual heavy minerals (avg percentage of heavy-mineral concentrate):	
Hornblende	19. 3
Epidote	15. 1
Sillimanite	6. 7
Ilmenite	33. 8
Leucoxene	2. 8
Rutile	5. 7
Zircon	9. 3
Monazite	1. 0

The samples were taken from the Oconee River in Wheeler County, the Ocmulgee River in Telfair County, and at sites along the Altamaha River in Wheeler, Toombs, Tattnall, and Long Counties.

Samples of sand from the Chattahoochee River where it enters the Coastal Plain at Columbus, Muscogee County, contain a small amount of monazite from the Piedmont, and the relative abundance of the monazite progressively increases downstream (Cazeau and Lund, 1959, p. 57). Concentrates at Columbus contain 0.1 percent of monazite. Concentrates from downstream localities at Fort Gaines, Clay County, and near the Florida State line at Seminole County contain respectively 0.4 and 0.9 percent of monazite (table 40).

TABLE 40.—*Mineralogical composition, in percent, of concentrates from the Chattahoochee River in the Coastal Plain of Georgia*

[Analyst: Cazeau and Lund (1959, p. 57, table 2)]

	Columbus	Fort Gaines	Seminole County
Monazite	0. 1	0. 4	0. 9
Rutile	. 7	2. 2	3. 1
Leucoxene	2. 9	5. 0	10. 5
Magnetite and ilmenite	12. 3	18. 4	17. 6
Staurolite	3. 6	4. 1	5. 2
Kyanite	12. 7	13. 4	15. 1
Tourmaline	3. 5	3. 3	3. 5
Zircon	2. 3	2. 3	2. 0
Epidote	18. 0	15. 0	14. 4
Hornblende	33. 9	31. 8	23. 7
Garnet	8. 1	1. 6	2. 5
Sillimanite	3. 5	1. 3	1. 1
Total	101. 6	98. 8	99. 6

The relative increase downstream in the abundance of monazite is accompanied by a similar relative increase in other stable heavy minerals. This increase was interpreted by Cazeau and Lund (1959, p. 56–57) as being mainly the result of the removal of unstable minerals from the total heavy mineral assemblage through solution during transport. Inasmuch as the absolute abundance of the minerals is not shown by weight, the increase in relative abundance shown by the percentage does not seem to be conclusive evidence for the residual enrichment in the most stable minerals. Unless the total weights of the concentrates decline harmoniously with the increase in the relative abundance of the stable species, modification of the suite by addition of stable minerals from the sedimentary formations of the Coastal Plain cannot be ruled out. In this connection the sample at Fort Gaines might well show an increase in monazite related principally to the addition of monazite from the sedimentary rocks at the head of Cemochechobee Creek in Randolph County, where Dryden (1958, p. 418) found that the McBean Formation contains 0.25 pound of monazite per cubic yard. Although the downstream change in composition of the concentrate is certainly affected by solution, particularly in the loss of magnetite which here unfortunately is obscured by inclusion of unstable magnetite with stable ilmenite, some changes in the mineralogical composition of the concentrate must also be attributable to influx of already weathered suites from the Coastal Plain rocks.

BEACHES OF THE SEA ISLANDS

The Sea Islands, a prominent physiographic feature of the coast of Georgia, and their beaches have been widely prospected for placer deposits of the titanium ores and monazite, but virtually nothing about the results of these systematic exploration programs has been published. Several articles have contained discussions of the composition of natural concentrates and raw unconcentrated sand from this region, and the following comments are drawn from them (Teas, 1921, p. 376–377; Martens, 1928, p. 142–144; 1935, p. 1584–1585; Neiheisel, 1962, p. 367–368, 371–374).

Two samples of natural concentrates and one sample of natural sand from the beach at Tybee, Chatham County, were examined by Martens and found to contain from a trace to 3 percent of monazite (table 41).

Natural black sand concentrates are generally present throughout Sapelo Island, McIntosh County, and are particularly conspicuous on the beaches and in an area a short distance north of the lighthouse at the south end of the island (Teas, 1921, p. 377). Dunes on Sapelo Island were said by Teas to have scant black sand. The presence of monazite, ilmenite, and zircon, in addition to large amounts of quartz, is indicated by chemical analyses of black sand from Sapelo Island (table 42).

St. Simon Island, Glynn County, was described by Teas (1921, p. 376) as having conspicuous deposits of black sand at the high tide line along the beaches. The largest of these deposits is at the south end of the island immediately in front of the lighthouse. At this locality a bed of sand 1 foot thick and half a mile long contains about 50 percent of black sand, and a layer 3 feet thick and about the same length was said by Teas to contain 2–10 percent of heavy minerals. Behind the high tide line the black sand is covered by dunes or a veneer of wind-shifted sand 1–10 feet thick. A chemical analysis of black sand from St. Simon Island is given in table 42. Mineralogical analyses of three natural concentrates from the upper part of the beach and a sample of natural sand from the beach were given by Martens and are listed in table 41.

Long Island, Glynn County, is separated by a marsh from the north end of St. Simon Island. Some black sand is present on the island and is most abundant near the crest of the beach ridge. A sample of natural concentrate from Long Island was described by Martens and is listed in table 41.

An excellent description of the geology of the monazite-bearing heavy-mineral deposits on Jekyll Island, Glynn County, was given by Neiheisel (1962, p. 371–374). His description is summarized as follows. Jekyll Island is 11 miles long from north to south and has a maximum width of 2 miles. At the north end the island is being eroded, and at its south end it is undergoing accretion. Dunes and sand ridges mainly parallel to the present beach extend across the island and reach a maximum height of 20 feet at the south end.

TABLE 41.—*Mineralogical composition, in percent, of concentrates from beach sand and natural concentrates on Sea Island beaches of Georgia*

[Samples 1–2 analyzed by Martens (1928, p. 144; 1935, p. 1584–1585); samples 3–5 analyzed by Neiheisel (1962, table 1, p. 368, 372). Symbols used: Tr., trace; --, absent]

	Tybee, Chatham County			St. Simon Island, Glynn County				Long Island, Glynn County	Jekyll Island, Glynn County			
	1	1	2	1	1	1	2	1	3	1	4	5
Total heavy minerals (percentage of raw sand):												
Range	--	--	--	--	--	--	--	--	1. 5–22. 5	50–90	5–30	1–5
Average or individual sample	55	92	4. 6	92. 8	88	90	0. 9	93. 3	6. 0	--	--	--
Individual heavy minerals (percentage of heavy-mineral concentrate):												
Ilmenite	53	62	27	49. 4	55	53	24	51. 1	39. 2	51. 0	42. 0	37. 2
Zircon	14	25	1	28. 6	29	31	3	27. 3	13. 2	16. 5	14. 3	13. 2
Rutile	4	3	1	5. 2	4	6	2	3. 8	5. 6	7. 5	5. 8	5. 2
Monazite	1	3	Tr.	4. 2	2	4	Tr.	2. 2	1. 2	3. 0	1. 2	1. 5
Staurolite	4	1	4	1. 3	2	1	6	1. 4	--	3. 0	3. 8	2. 7
Epidote	15	4	33	2. 0	5	2	26	4. 2	14. 8	10. 0	14. 5	16. 0
Garnet	1	1	1	. 9	1	1	Tr.	1. 0	--	1. 0	1. 0	1. 1
Kyanite	Tr.	Tr.	1	. 3	Tr.	Tr.	3	. 2	--	Tr.	1. 3	1. 6
Sillimanite	Tr.	Tr.	6	. 3	Tr.	Tr.	6	. 4	7. 3	3. 0	6. 0	7. 8
Tourmaline	Tr.	Tr.	4	. 04	Tr.	Tr.	3	. 1	--	. 5	1. 3	1. 8
Hornblende	2	Tr.	12	. 1	Tr.	Tr.	12	. 4	7. 1	2. 0	4. 2	9. 1
Leucoxene	2	Tr.	2	. 4	1	Tr.	2	. 5	2. 7	2. 0	2. 8	1. 5
Sphene	Tr.	Tr.	Tr.	--	Tr.	--	Tr.	. 05	--	--	--	--
Spinel	Tr.	Tr.	--	. 08	Tr.	Tr.	--	Tr.	--	--	--	--
Corundum	Tr.	--	--	--	--	--	--	--	--	--	--	--
Andalusite	--	--	Tr.	--	--	--	--	--	--	--	--	--
Collophane	2	Tr.	7	. 2	Tr.	Tr.	11	. 4	--	--	--	--
Anatase	--	--	--	Tr.	--	Tr.	--	--	--	--	--	--
Zoisite	--	--	Tr.	--	--	--	Tr.	--	--	--	--	--
Hypersthene	--	--	Tr.	--	--	--	--	--	--	--	--	--
Other minerals	--	--	Tr.	7. 1	--	--	--	6. 9	--	. 5	1. 3	1. 3

1. Natural heavy-mineral concentrate.
2. Concentrate prepared from natural sand.
3. Average of 17 samples of natural sand.
4. Concentrations in foredunes.
5. Natural dune sand.

TABLE 42.—*Chemical analyses, in percent, of black sand from Sapelo Island and St. Simon Island, Ga.*

[Modified from Teas (1921, p. 376–377)]

	Sapelo Island		St. Simon Island
	A	B	
K_2O	1.06		
Na_2O	1.19		
CaO	1.08	0.37	0.00
MgO	.12	.17	.00
Al_2O_3	.91		.00
Fe_2O_3	.43	5.16	7.84
FeO	.86	8.36	11.29
MnO	.32	Trace	1.89
TiO_2	5.55	5.23	34.40
P_2O_5	.49	.28	.18
SiO_2	85.78	80.15	43.12
ThO_2	.24		.28
Ce_2O_3	.40	.18	[1].51
ZrO_2	.10	.08	.12
Cl	.15		
S	.11		
H_2O at 100° C	.18		
Loss on ignition	1.03		
Total	100.00	99.98	99.63

[1] Given as 0.53 percent CeO_2.

Along the front ocean beach the direction of transport of sediment is from north to south in the direction of the predominant alongshore current. Concentrations in which heavy minerals make up as much as 75 percent of the sand are found at the south end of Jekyll Island in thin black surface layers on the upper beach, in thin horizontal black beds extending toward the shore beneath dunes, and in crossbedded layers in the dunes. Heavy minerals are also disseminated through the beach and dune sands in low concentrations of 1–5 percent. The average mineralogical composition of 17 samples of black sand from Jekyll Island is shown in table 41, together with examples of natural concentrates from the upper beach and foredunes and natural dune sand. The mineral species are similar in all occurrences on the island but differ in their degree of concentration according to their mode of deposition. The outer shore of the island, and probably of the other Sea Islands, is the most favorable location for the discovery of exploitable heavy-mineral deposits.

Displays of above-background radioactivity were observed by Moxham and Johnson (1953) along the Atlantic Ocean beach of Georgia. Presumably the main source of the radioactivity is monazite in littoral black sands. Four areas of above-background radioactivity are beaches described in the preceding paragraphs as being enriched in monazite: Savannah Beach in the Tybee area, Chatham County; Sapelo Island, McIntosh County; St. Simon Island immediately north of Sea Island Beach; and Jekyll Island. Above-background radioactivity was also noted on the Atlantic beaches of Skidaway Island, Chatham County; Ossabaw Island, Bryan County; and the north and south ends of St. Catherines Island, Liberty County.

IDAHO

Monazite was discovered in about 1896 in the Boise River basin by Waldemar Lindgren of the U.S. Geological Survey who identified it in panned concentrates from gold placers on Moore Creek and Granite Creek and in concentrates from lake beds near Idaho City, Boise County (Lindgren, 1897, p. 63; 1898, p. 677). He also found that monazite was present in granite adjacent to the placers; thus, with the initial identification of the detrital monazite the primary source was also found. Subsequently, occurrences of monazite were noted as far south as Oreana, Jordan Creek, and Rabbit Creek in Owyhee County (Day and Richards, 1906b, p. 1200–1201; Staley, 1940, p. 4; Hubbard, 1955, fig.); as far north as Shoshone County (Day, 1905a, p. 9); as far west as the Clearwater River at Lewiston in Nez Perce County, and the Snake River in Adams County (Day and Richards, 1906b, p. 1200–1201; Schrader and others, 1917, p. 119); and as far east as Bannock County (Day, 1905a, p. 9). In 1950 monazite was discovered in pegmatite in northern Lemhi County between North Fork and Shoup, and shortly thereafter it was found to have a wide distribution in carbonatite in the same area (Trites and Tooker, 1952, fig. 1; Abbott, 1954, p. 3; Anderson, A. L., 1960, p. 1179). The monazite contains very little thorium, but other thorium-bearing minerals in the deposits and in the neighboring Lemhi Pass district make the Lemhi County area and adjacent parts of Montana a possible important source for thorium.

Experiments directed toward the production of monazite from gold placer concentrates were said to have been begun in Idaho in the early 1900's by the Centerville Mining and Milling Co. at Centerville, Boise County (Pratt, 1916, p. 62). No production was recorded until 1906 when 2 or 3 short tons of monazite was separated from black sand recovered at the gold placers, but this small output was not marketed (Pratt, 1916, p. 62–63; Sterrett, 1908b, p. 273; Cook, 1957, p. 4). During the period 1907 through 1910 similar small production was reported to have been achieved at the Centerville operation, but none of the monazite was shipped because it cost more per pound to process than the Carolina monazite (Pratt, 1916, p. 64). At least one report stated that Idaho was a factor in the monazite industry in the United States during the early 1900's and attributed a small but continuous output to the Centerville plant from 1903 through 1910 (Santmyers, 1930, p. 14). The contemporary literature, however, although careful to state that records were not maintained at the Centerville operation, clearly shows that monazite from Centerville did not enter the domestic market. In 1910 the plant was destroyed by forest fire and was not rebuilt (Sterrett, 1911, p. 901; Staley and Browning, 1949, p. 2; Kline and others, 1950, p. 24; Kauffman and Baber, 1956, p. 3). With the entrance of cheap, thorium oxide-rich monazite from India into world commerce in 1911 (Houk, 1946, p. 11–12), the domestic monazite mining industry closed. Except for a small supply from the Carolinas and Florida between 1915 and 1917, the United States imported monazite until the early 1950's.

Interest in domestic sources of monazite as an ore of thorium and the rare earths was renewed in the late 1940's after India, the main supplier to the United States, placed an embargo on the export of monazite in 1946. Between 1946 and 1948 monazite-bearing jig concentrates from dredges operated by Baumhoff-Marshall, Inc., and the Idaho-Canadian Dredging Co. on gold placers in Grimes Creek and Granite Creek in the Boise River basin, Boise County, supplied 40 short tons of monazite (Kline and others, 1950, p. 24). Possibly some of this material was represented in the four analyses of monazite concentrates from Idaho showing 1.75–3.66 percent of ThO_2 published by the U.S. Atomic Energy Commission (George, 1949, p. 117). In mid-1948 the School of Mines at the University of Idaho called attention to the old reports on the occurrence of monazite in the State, and an announcement was made that Boise and Idaho Counties alone had 200 million cubic yards of placer ground estimated to contain 0.2–0.3 percent of monazite (Mining Cong. Jour., 1948). In October 1948 the U.S. Bureau of Mines made a reconnaissance of the monazite-bearing gold placers in the Boise basin, and in August 1949, with support from the U.S. Atomic Energy Commission, the Bureau commenced exploration of these placers (Kline and others, 1950, p. 4–5; Griffith, 1955, p. 930). In the following year, exploration was undertaken in the Big Creek area near Cascade, Valley

County. Drilling on Big Creek was completed in September 1950. In November 1950 private interests began to erect a 6-cubic-foot bucket-line dredge, and in January 1951 they commenced to mine monazite which was the only saleable product from the placer (Lamb, 1955b, p. 4; Eilertsen and Lamb, 1956, p. 25). Late in 1951 two more dredges were introduced in the Big Creek area (Kline and Carlson, 1954, p. 13). One dredge capsized in May 1953; the equipment was salvaged in 1954 but was not put back in operation (Kauffman and Baber, 1956, p. 11; Crawford, 1958a, p. 1157–1158). The two remaining dredges were said to handle about 4,000–6,000 cubic yards of gravel each per day and to recover about 2 short tons of monazite each per day (Lamb, 1955a).

By the end of 1951 Baumhoff-Marshall, Inc., was reported to have shipped 1,000 short tons of monazite to the Lindsay Light and Chemical Co. (Eng. and Mining Jour., 1952b), and in the following years the total average output of the dredges in the Cascade area was expected to be 3,000–5,000 short tons of monazite per year (Mining Jour., 1954a, p. 97). These dredges operated until August 1955 when the United States Government stockpile requirements for monazite were filled. After that date, contracts with the Government or private industry were no longer obtainable owing to the filling of the stockpile requirements and the resumption of imports of thorium oxide-rich monazite.

From 1950 to 1952 the Bear Valley area in Valley County was explored by the U.S. Bureau of Mines (Kline and others, 1953, p. 5). The placers were found to contain monazite, euxenite, and ilmenite with small amounts of samarskite, fergusonite, columbite, and other minerals. In 1955 two dredges were installed in Bear Valley by private interests because of a demand for euxenite, and as late as 1958 byproduct monazite was being recovered (Eilertsen and Lamb, 1956, p. 25; Crawford, 1957b; Lewis, 1959, p. 1).

Complete figures for the output of monazite in Idaho during the 1950's have not been officially released owing to several causes, among which are the protection of individual producer's interests and the interests of national security. It is likely that several thousand short tons of monazite a year was produced in the State from 1952 through 1955, and a smaller output was sustained at least through 1958.

CRYSTALLINE ROCKS

Monazite is one of the minor accessory minerals in the Idaho batholith, and several occurrences have been mentioned, usually in connection with descriptions of detritus from the crystalline rocks (Ross, C. P., 1941, p. 107). A systematic discussion of monazite in the batholith, however, had not been published by the time this review was written in 1962. The scattered occurrences that were described and the information on the composition of monazite in the placers seem to the writer to indicate that the distribution and composition of the monazite are geologically controlled, but the nature of the control is not known.

Factors that suggest to the writer that the presence of monazite in the batholith is controlled by regional processes are as follows: The abundance of thorium oxide in the monazite seems to vary regionally, and the average amount of thorium oxide is low; the monazite is associated with allanite, but it has a restricted occurrence, whereas the allanite is found throughout the batholith; the monazite is very scarce in the wallrocks; and the physical properties of the monazite are uniform.

The amount of thorium oxide in the monazite seems generally to increase southward. Abundances of 2.2 and 3.3 percent of ThO_2 were reported for monazite from streams in Nez Perce and Clearwater Counties (Staley, 1952, p. 308; Schrader, 1910, p. 188), and 2.7, 3.69, and 5.75 percent for monazite in central and southern Idaho County (Staley, 1952, p. 306; Kauffman and Baber, 1956, p. 6). These analyses of samples of monazite from localities scattered over the northern part of the west side of the batholith, or downstream from this area, average 3.3 percent of ThO_2. As early as 1910 it was said that a large number of concentrates from northern Idaho, averaging about 90 percent of monazite, contained only about 3 percent of ThO_2 (Schrader, 1910, p. 188). Results of 16 analyses of monazite from Valley County and 1 from Custer County in the west-central part of the batholith show from 3.31–4.84 percent of ThO_2 and average 4.27 percent of ThO_2 (Kline and others, 1953, p. 20; Kline and Carlson, 1954, p. 21–22; Storch and Robertson, 1954, p. 13; Kauffman and Baber, 1956, p. 6). Monazite from the most southerly parts of the batholith explored in Boise and Elmore Counties has been shown in 12 analyses to contain from 2.9–6.24 percent of ThO_2 (Salt Lake Mining Rev., 1910; Sterrett, 1911, p. 902–903; Kline and others, 1950, p. 32; Kauffman and Baber, 1956, p. 6). Of these 12 analyses, 9 are from the Boise basin, and they have the low average tenor of 3.9 percent of ThO_2. The three samples of monazite from localities south of the basin have an average of 5.9 percent of ThO_2, and the average of the 12 analyses is 4.4 percent of ThO_2. Although there is local variation in the abundance of thorium oxide in the monazite, the 34 analyses indicate that the average amount of ThO_2 in the monazite is 4 percent, and the average content of ThO_2 increases from 3.3 percent in the northern part of the batholith to 4.4 percent in the southern part. The low average amount of ThO_2, 4 percent, is elsewhere in the world commonly associated with monazite occurring in granitic rocks that are not very plutonic and that are associated with regional metamorphism of low to intermediate grade, generally ranging from the albite-epidote-amphibolite facies to the kyanite-staurolite subfacies.

Granitic rocks having monazite that contains about 4 percent of ThO_2 generally have accessory allanite. Monazite seems to be far less abundant in the batholith as a whole than allanite (Anderson, 1952, p. 257, 260), and where monazite is unreported allanite has generally been observed (Anderson, A. L., 1942, p. 1100, 1106–1107, 1112, 1118). In the eastern and northern parts of the batholith, monazite is much less common than allanite, and the trend seems to continue into the separate granitic mass in the northern part of the State where granodiorite in the Pend Oreille district, Boundary County, was reported to contain allanite but not monazite (Gillson, 1927, p. 27). In the western and southern parts of the batholith, monazite was said to be present in more places than not, but its gross distribution is not uniform; at some places it is unaccompanied by allanite (Mackin and Schmidt, 1957, p. 2). Allanite throughout the batholith was described by A. L. Anderson (1942, p. 1118–1119) as having been formed by endomorphic alteration under gradually changing conditions of temperature and pressure. In the opinion of Mackin and Schmidt (1957, p. 3), the radioactive minerals formed at the same time as the host rocks instead of being deposited later by hydrothermal solutions. It is not known if the apparent antipathetic relations of monazite and allanite are genetic. For an understanding of the origin of the monazite it seems necessary to learn whether or not allanite proxies for monazite as a host for rare earths and thorium under conditions of lower temperature and pressure, either igneous or metamorphic, that do not favor development of monazite. This relationship between monazite and allanite plus sphene has been observed in the granitic rocks of the Ukrainian shield (Vainshtein and others, 1956, p. 174).

The metasedimentary rocks adjacent to the batholith were said to be very nearly devoid of monazite except for the replacement deposits to the northeast in Lemhi County. Along the west edge of the batholith the migmatites adjacent to monazite-bearing quartz monzonite contain practically no monazite (Mackin and Schmidt, 1957, p. 2). Monazite is generally absent from the Precambrian rocks east of the batholith (Staley, 1952, p. 305; Shockey, 1957, p. 8). Absence of monazite from metasedimentary rocks adjacent to monazite-bearing intrusive rocks is a common feature of relatively shallow intrusives elsewhere in the world.

Monazite from different localities in the Idaho batholith was described by Shannon (1926, p. 411–414) as having similar physical properties. It is commonly resinuous golden yellow to amber or orange brown; very rarely it is colorless or green. The grains from most localities have the same few crystal forms, a simple crystal habit being characteristic. Inclusions are scarce, and small crystals are commonly flawless and transparent. Large grains are commonly opaque owing to multiple cracks. Such similarity in physical properties suggests a common autochthonous origin.

The sporadic distribution of the monazite in the batholith, its general absence from the wallrocks, the common presence of allanite in the batholith, and the amount of thorium oxide in the monazite seem to this writer to indicate that the monazite formed in the batholith along with the host minerals at comparatively shallow depth. The monazite-bearing zone along the western part of the batholith seems to display a regional variation in the chemical composition of the monazite that may be related to increasingly plutonic conditions of crystallization toward the south. With these inferences as a guide it is postulated in the section on "Placers" that monazite richer in thorium oxide than any yet found in the Idaho batholith may occur in granitic terrain south and southwest of the presently exposed south margin of the main mass of the batholith.

The other principal source of thorium minerals in Idaho, the replacement and vein deposits in Lemhi County on the east side of the batholith, seem to have formed very late in the history of emplacement of the batholith or after emplacement. Probably this group of deposits is not related to the Idaho batholith. Monazite from these deposits is lean in or devoid of thorium; however, substantial reserves of thorium are present in allanite and thorite. The replacement and vein deposits have been discussed in detail in several reports, but the occurrences of monazite in the rocks of the Idaho batholith have received little close attention despite the frequency with which they have been mentioned in the literature. Therefore, the descriptions given in the following paragraphs of monazite in the batholith are little more than locality references.

Where the North Fork of the Clearwater River and Elk Creek cut through the Columbia River basalts near Dent in Clearwater County, they expose small masses of monazite-bearing granite and schist

(Schrader, 1910, p. 190). Schrader (1910, p. 189) noted that accessory monazite can be observed with the aid of a hand lens in granite exposed locally near Musselshell Creek, a tributary to Lolo Creek in Clearwater County. Disintegrated granite in the main valleys of the Orofino district contains accessory monazite (Anderson, A. L., 1930, p. 61). The Elk City region in Idaho County is underlain by biotite gneiss which was thought by R. R. Reid (1960) to be monazite bearing.

In the Warren district, Idaho County, monazite was observed by Bell (1904, p. 224) in granite of the Idaho batholith and, in small quantities, in rich gold-quartz veins. Except for quartz veins in the Lemhi Pass area, this is the only district where monazite has been reported in quartz veins in Idaho.

Porphyritic biotite granodiorite of the Idaho batholith exposed near the Big Creek Ranger Station and at a point 2,000 feet north-northwest of Peak 8520 near the Pilot Peak trail in the Big Creek quadrangle, Valley County, contains accessory monazite (Jaffe and others, 1959, p. 93).

Granite porphyry and aplite dikes of the Idaho batholith exposed east of the south half of Long Valley in Valley County contain monazite, but metasedimentary rocks on the west side of the valley have little or no monazite (Kline and others, 1955, p. 8–9). Granite exposed in Valley County between Peace Valley on the Middle Fork of the Payette River and Garden Valley in Boise County contains accessory monazite (Jaffe and others, 1959, p. 95).

Monazite was observed in granite in the Boise basin, Boise County, about 1896 by Lindgren (1898, p. 677). A large pegmatite dike thought to be related to the rocks of the Idaho batholith and exposed between Garden Valley and Grimes Pass, Boise County, was said to contain veinlets of almost pure monazite (Staley, 1952, p. 303). Uranium, niobium, and tantalum minerals have been found in this dike. The assemblage of metals resembles in part that reported from the vein and lode deposits of northeastern Lemhi County, but the mode of occurrence is different.

REPLACEMENT DEPOSITS AND VEINS

Two important thorium districts are situated in northern Lemhi County, Idaho, and adjacent parts of Ravalli and Beaverhead Counties, Mont. The more northerly of the two is known as the Mineral Hill district and the other is called the Lemhi Pass district. Discovery of monazite in the Mineral Hill district was made by Trites and Tooker (1953, p. 164–186) of the U.S. Geological Survey in 1950, and deposits in the Lemhi Pass district were discovered by Vhay (1950, p. 1–17) of the Survey in 1949. In 1952 the Mineral Hill district was observed by Abbott (1954, p. 2) to be far more extensively mineralized than was noted at the time of discovery. Since then the size and origin of the deposits in both districts have received considerable attention (Sharp and Cavender, 1953; Kaiser, 1956; Weis and others, 1958, p. 39–40; Anderson, A. L., 1958, p. 21–77; 1960, p. 1180–1201).

Sparse monazite was seen by Trites and Tooker in 1950 (1953, p. 164) in the plagioclase-muscovite-quartz-perthite wall zone and the perthite-plagioclase-muscovite-quartz intermediate zone of the Snowdrift pegmatite dike 3 miles east of Shoup and 0.5 mile north of the Salmon River in Lemhi County. The dike, which is in porphyroblastic paragneiss, was not considered to be a source of monazite. Although this occurrence in pegmatite is the first report of monazite in the Mineral Hill district, the extensive deposits of low-thorium oxide monazite in carbonate rocks exposed between Shoup and North Fork were not discovered until 1952 (Abbott, 1954, p. 3). The carbonate rocks were first called phosphatic marble, but later work showed them to be carbonatites (Anderson, A. L., 1960).

Crystalline aggregates and disseminated crystals of monazite occur in thin masses of carbonatite exposed east of the Snowdrift pegmatite. The monazite-bearing layers were found to be most abundant in a belt about 1.5 miles wide and 18 miles long which is part of a linear group of occurrences 2.5 miles wide and 25 miles or more long that extends northwestward from a point about 4 miles south of North Fork, Lemhi County, at least to Woods Creek in Ravalli County, Montana (Weis and others, 1958, p. 39; Anderson, A. L., 1958, p. 21). The deposits are in an area underlain mainly by biotite gneiss, schist, and amphibolite, with subordinate quartzite. Biotite gneiss is the most common variety of rock. Its principal constituents are feldspar, quartz, and biotite, which vary locally in proportion, size, and textural arrangement. Some of the biotite gneiss is strikingly porphyroblastic and resembles augen gneiss or coarse-grained granite (Anderson, A. L., 1958, p. 22). These rocks are locally intruded by little disturbed dikes of metadiabase, two types of pegmatite, and rhyolite. One type of pegmatite is unzoned and is composed chiefly of potassium feldspar and quartz. Locally it contains scattered grains of allanite. The other type of pegmatite, to which the Snowdrift dike belongs, is coarse grained, zoned, and contains book muscovite and sparse monazite. There are no rare-earth minerals in the rhyolite dikes (Abbott, 1954, p. 10).

The biotitic gneisses and schists are interpreted by Abbott (1954, p. 5–10) and Kaiser (1956, p. 8) to be of sedimentary origin. The amphibolites were regarded by A. L. Anderson (1960, p. 1182) to be intrusive gabbroic rock greatly modified by shearing and metamorphism. Where deformation and metamorphism are least intense, the schistose and gneissic amphibolite shows transition into massive gabbro. Abbott and Kaiser regarded the monazite-bearing carbonate rock as sedimentary limestone altered by metamorphism, but Anderson has shown by the chemical and mineralogical composition of this rock that it is a carbonatite.

The regional structure of the Mineral Hill district was interpreted by Abbott (1954, p. 12) and Kaiser (1956, p. 12) to be a complex overturned synclinorium, the monazite deposits being localized in the axial parts. At its southeast end the belt of monazite-bearing rocks is intruded by granite probably related to the Idaho batholith, and the northeast edge of the gneisses is in fault contact with quartzite belonging to the Belt Series.

Crystalline aggregates and disseminated crystals of monazite are associated with allanite, ilmenorutile, apatite, and other minerals in the carbonate veins and, to a lesser extent, in the biotitic metamorphosed sediments (Anderson, A. L., 1960, p. 1184–1196). The greatest concentrations of monazite-bearing carbonatites are on the crests or troughs of folds, and, less commonly, along the limbs of folds. Exceptionally, the monazite-rich carbonatites may reach a thickness of 8 feet and a length of 1,000 feet, but most of them are only 1 or 2 feet thick and not more than 20 feet long.

Monazite in the southeastern part of the belt of deposits contains more thorium and is more radioactive than that elsewhere in the district (Weis and others, 1958, p. 39). Most of the monazite was reported to be weakly radioactive and to contain less than 1 percent of ThO_2 (Anderson, A. L., 1960, p. 1188). Three samples of monazite from the Mineral Hill district were analyzed by Jaffe, Gottfried, Waring, and Worthing (1959, p. 96–97) of the U.S. Geological Survey and found to have the low activity of 578–1024 alpha particles per milligram per hour. An analysis by the U.S. Bureau of Mines disclosed 0.85 percent of ThO_2 and 0.003 percent of U_3O_8 (Kauffman and Baber, 1956, p. 6). The accompanying allanite is very radioactive and may contain much of the thorium in the district (Anderson, A. L., 1960, p. 1187).

A. L. Anderson (1960, p. 1200) regarded the mineral assemblage of the monazite deposits in the Mineral Hill district to be typical of other carbonatites and hence to have been formed by late-stage magmatic processes. The richness of the assemblage in thorium, rare earths, phosphorus, niobium, titanium, barium, calcium, iron, and sulfur is similar to the characteristic association of elements in carbonatites related to alkalic intrusives of igneous origin; however, there are no known alkalic intrusives in the district.

The Lemhi Pass thorium district in Lemhi County, has been described by several authors (Vhay, 1950; Trites and Tooker, 1953, p. 191–205; Sharp and Cavender, 1953; Anderson, A. L., 1958, p. 45–58). In the following summary, the account of the geology is mainly from A. L. Anderson.

The Lemhi Pass district occupies 100 square miles of the Beaverhead Range, 26 miles southeast of Salmon. In the district, veins and lodes of thorite associated with monazite, specular hematite, barite, feldspar and quartz occur in folded and faulted weakly metamorphosed muscovite quartzite and biotite-chlorite phyllite of the Precambrian Belt Series of sedimentary rocks. The veins are principally composed of quartz, hematite, and thorite, with or without sulfides. Intrusive into the Belt sediments are small dioritic and lamprophyric dikes of possible Late Cretaceous or early Tertiary age. Locally the old rocks are covered by volcanic rocks of Oligocene(?) age, Tertiary lake beds, and Quaternary terrace gravels and alluvium. In some deposits the thorite and rare-earth minerals were introduced into earlier quartz veins and copper-bearing lodes. In other deposits the thorium minerals occur along previously unmineralized shears and fractures most of which are 40–60 feet across. Monazite, thorite, and specular hematite impregnate and replace the sheared rocks. Locally these minerals are accompanied by fine-grained sericite, allanite, apatite, xenotime(?), calcite, magnetite, biotite, and pyrite. Monazite forms small euhedral crystals or occurs as irregular-shaped inclusions in barite, feldspar, and quartz. Rarely and locally the monazite mantles thorite.

The minerals in these deposits were interpreted by A. L. Anderson (1958, p. 57) to have been introduced by fluids enriched in thorium, rare earths, phosphorus, iron, potassium, barium, calcium, and sulfur, and less enriched in carbon dioxide. This association resembles end products formed from alkalic magma. It is like the association in the Mineral Hill district except that it lacks the abundant carbonate, titanium, and columbium present there. Also, the Lemhi Pass deposits are richer in thorium, potassium, and silicon than those at Mineral Hill. Quartz is the most common gangue mineral at Lemhi Pass; carbonates are the most common gangue at Mineral Hill. The deposits may be related to dioritic intrusives that are younger than the Idaho batholith.

Monazite and thorite are present in shear zones and gold quartz veins in the Diamond Creek area, Lemhi County, about 7 miles north-northwest of Salmon (Anderson, A. L., 1958, p. 74–77). The thorium deposits are in and adjacent to the east side of a stock of very coarse grained granite that intrudes micaceous quartzite and schist of the Belt Series. The mineralogy of these deposits, though complex, differs but slightly from that of the thorium deposits in the Lemhi Pass area. As far as is known the only difference is the presence of fluorite in the veins at Diamond Creek. Deposition of the minerals in the deposits in the Diamond Creek area was thought by Anderson to have taken place in the same order as that at the Lemhi Pass district: thorite first followed by monazite, apatite(?), xenotime(?), specular hematite, barite, feldspar, and quartz. These deposits, like those at Lemhi Pass, were interpreted by A. L. Anderson (1958, p. 77) to be related to dioritic intrusives slightly younger than the Idaho batholith.

Monazite concentrates were said to have been shipped from Hall Mountain near Porthill, Boundary County, in northern Idaho (Gillson, 1958, p. 101), but the Porthill deposits were described as thorite-bearing veins, and the presence of monazite was not indicated (Weis and others, 1958, p. 34–35).

PLACERS

The mined monazite placers lie along the west side of the Idaho batholith in the west-central part of the State, but several occurrences of detrital monazite have been mentioned from other parts of Idaho. The richness of the mined placers was said by Mackin and Schmidt (1956, p. 376–377) to depend upon the abundance of monazite in the rocks of the Idaho batholith and on the physiographic history of the individual drainage basin. Monazite is most common in quartz monzonitic phases of the batholith. It tends to occur in erratic microscopic segregations which contain as much as 0.3 pound of monazite per cubic yard of rock. The best placers were formed where the quartz monzonite has the greatest number and richest segregations of monazite, where the rock was thoroughly weathered during middle Pleistocene time, and where thick alluvial fills accumulated under conditions allowing for maximum sorting by the streams (Mackin and Schmidt, 1956, p. 376–377).

The amount of thorium oxide in monazite from the exploited placers is low by commercial standards, being only about 4 percent whereas market specifications usually demand 6 percent or more of ThO_2. If the apparent regional southward increase in thorium oxide in monazite from the Idaho batholith, mentioned in the section under crystalline rocks, is real, then it is possible that the trend continues to the south of the limit of exposure of the batholith in Elmore and Camas Counties. Monazite having as much as 6 percent of ThO_2 may be present in granitic rocks in Owyhee and Minidoka Counties, Idaho, or, as a remote possibility, in Humboldt and Elk Counties, Nev. Systematic prospecting for monazite around granite bodies south and southwest of the exposed south margin of the batholith might disclose thorium oxide-rich monazite in workable placers. If this monazite were found, it would be a more marketable commodity than monazite from the Boise basin.

The placers and known occurrences of detrital monazite are described in geographic order from north to south and from west to east; therefore, discussion of the economically important deposits is interspersed with descriptions of occurrences that may be scarcely more than mineralogical curiosities.

SHOSHONE, LATAH, CLEARWATER, AND NEZ PERCE COUNTIES

Black sand from placers at unspecified localities in Shoshone and Latah Counties was stated to contain monazite (Day, 1905a, p. 9).

Detrital monazite has been reported from six localities in Clearwater County: Elk River; Dent; Orofino; Orofino Creek; Pierce district including Cow Creek and Rhodes Creek; and Musselshell Creek and an area 10 miles from Weippe. No information other than the location has been given for placers at the settlement of Elk River in the Elk Creek valley (Savage, 1960, fig. 1). Natural sand and placer concentrates from Dent, Orofino, and the Pierce district were reported by Day and Richards (1906b, p. 1198–1201; 1907, p. 24–27) to contain from a trace to 283 pounds of monazite per short ton (table 43). The placer occurrences around Dent were apparently not described in detail, though they were mentioned by Schrader, Stone, and Sanford (1917, p. 119), DeMent and Dake (1948, p. 18), and Dake (1955, p. 56).

Monazite-bearing fluvial placers in the Orofino district of Clearwater County were described by A. L. Anderson (1930, p. 61–62). The placers are found along the valley floors of streams and in gravel that caps the lower ridges or forms terraces along the valley walls. Monazite is commonly associated with gold, garnet, magnetite, ilmenite, rutile, chromite, and zircon. It tends to be more abundant in the lower part of the sequences of sediments, especially in gravel immediately above granitic bedrock. Monazite is more abundant in the old terrace gravel than in the gravel of the present stream channel. Low concentrations of monazite occur in residual soil, talus, and disintegrated

TABLE 43.—*Mineralogical composition, pounds per short ton, in auriferous natural sand and concentrates from placers in Idaho*

[Modified from Day and Richards, 1906, p. 1194–1201; Tr., trace; —, absent]

Sample	Location	County	Magnetite	Chromite	Ilmenite	Garnet	Monazite	Zircon	Quartz	Others	Source
1	Dent	Clearwater	6	280	540	414	126	--	586	26	Placer concentrate.
2	do	do	Tr.	1,432	--	265	52	--	--	--	Do.
[1] 3	do	do	28	1,336	--	307	283	--	45	--	Do.
[1] 4	Orofino	do	768	--	1,000	20	88	76	24	20	Do.
5	do	do	78	--	244	40	6	2	1,440	190	Natural sand.
6	Pierce	do	50	--	1,450	--	94	50	226	130	Placer concentrate.
7	do	do	10	6	62	28	3	3	1,471	409	Natural gravel.
8	do	do	1	--	12	11	.1	--	1,766	207	Gravel tailing.
9	do	do	4	--	106	24	Tr.	Tr.	1,528	338	Do.
[1] 10	do	do	2	--	17	4	2	--	1,473	499	Do.
11	do	do	24	--	1,806	--	30	30	--	90	Placer concentrate.
[2] 12	Pierce district	do	72	--	1,360	320	70	150	--	28	Do.
13	do	do	.2	--	1,189	--	81	14	654	59	Undescribed.
14	Pierce district, Cow Creek.	do	3	--	1,351	199	46	--	300	93	Placer concentrate.
15	do	do	2	--	1,080	413	50	.6	358	96	Do.
16	Pierce district, Rhodes Creek.	do	48	--	1,376	--	Tr.	80	400	100	Do.
17	Clearwater River, Lewiston.	Nez Perce	90	--	580	360	Tr.	30	760	160	Do.
18	Salmon River	do	981	688	--	113	46	122	12	36	Undescribed.
19	Elk City	Idaho	978	--	336	--	26	18	270	340	Placer concentrate.
20	do	do	60	--	210	10	40	10	1,520	160	Undescribed.
21	do	do	208	1,317	--	--	108	--	334	33	Do.
22	Elk City district	do	1,162	--	428	--	6	6	384	14	Do.
[2] 23	do	do	80	--	696	296	728	Tr.	--	200	Placer concentrate.
24	do	do	--	--	720	120	808	120	--	104	Undescribed.
[2] 25	Baker Gulch, Crooked River.	do	720	--	624	--	320	--	--	336	Do.
26	Penmans Fork, Big Creek.	do	640	--	520	80	528	Tr.	224	--	Placer concentrate.
27	Florence	do	--	--	1,520	160	Tr.	--	320	--	Undescribed.
28	Marshall Lake district.	do	80	--	136	--	376	1,408	--	--	Placer concentrate.
29	Syringa	do	192	--	1,584	--	Tr.	--	224	--	Do.
30	Camp Howard district.	do	1,285	--	308	153	Tr.	100	--	154	Do.
31	Resort	do	196	--	470	--	112	--	638	584	Do.
32	Lardo	Valley	1,480	--	250	210	20	30	--	10	Do.
33	Meadows	Adams	629	564	--	Tr.	123	392	232	--	Do.
34	do	do	.5	--	16	4	.1	1	1,274	704	Undescribed.
35	Payette River	Payette	1,744	--	100	40	6	8	--	100	Natural sand.
36	Garden Valley	Boise	1,864	--	56	16	32	24	--	Tr.	Placer concentrate.
37	Placerville	do	182	--	26	--	142	12	--	42	Undescribed.
38	do	do	68	Tr.	90	--	36	4	--	--	Do.
39	do	do	1,448	--	198	--	170	34	106	44	Placer concentrate.
40	Centerville	do	6	18	--	Tr.	2	Tr.	104	1,870	Undescribed.
41	do	do	12	--	38	38	286	90	--	--	Do.
42	do	do	6	14	32	14	4	6	--	--	Do.
43	do	do	Tr.	Tr.	8	Tr.	Tr.	Tr.	--	--	Do.
44	do	do	4	2	10	2	4	2	--	--	Do.
45	Centerville district	do	864	--	568	128	224	100	120	--	Placer concentrate.
[1] 46	Grimes Creek, Centerville district.	do	264	--	782	--	358	--	556	438	Abandoned placer.
[1] 47	do	do	1,624	--	102	--	240	36	--	--	Do.
48	do	do	330	--	702	--	68	--	892	10	Undescribed.
49	do	do	396	--	792	--	Tr.	--	762	52	Do.
50	do	do	244	337	347	29	30	12	1,251	80	Do.
51	Idaho City	do	82	--	378	414	42	360	642	82	Do.
52	Boise area	Ada	26	200	--	709	219.6	231	579	--	Do.
[1] 53	do	do	540	--	826	--	94	34	382	124	Do.
[1] 54	do	do	38	1	--	2	27.3	27	1,735	168	Do.
[1] 55	do	do	1,629	2	2	--	58.7	8	49	249	Placer concentrate.
56	do	do	216	80	248	400	Tr.	Tr.	1,000	136	Undescribed.
57	do	do	1,244	--	344	--	250	6	106	48	Do.
58	Oreana	Owyhee	32	--	1,472	40	56	--	340	80	Do.
[2] 59	Leesburg Basin	Lemhi	1,807	--	--	37	20	--	135	--	Do.
60	do	do	192	--	1,340	--	44	200	--	224	Do.
61	do	do	433	477	--	--	10	--	65	--	Do.
[1] 62	do	do	1,939	1	--	4	.5	.9	8	--	Do.
63	Arnet Creek, Leesburg Basin.	do	959	832	--	116	.5	1	--	--	Do.

See footnotes at end of table.

TABLE 43.—*Mineralogical composition, pounds per short ton, in auriferous natural sand and concentrates from placers in Idaho*—Con.

Sample	Location	County	Magnetite	Chromite	Ilmenite	Garnet	Monazite	Zircon	Quartz	Others	Source
64	Wards Gulch, Leesburg Basin.	Lemhi	747	859	--	128	5	60	73	--	Undescribed.
65	Shoshone	Lincoln	174	15	--	80	26	46	1, 441	--	Do.
66	Minidoka	Minidoka	Tr.	--	Tr.	Tr.	8	Tr.	--	--	Do.
67	Snake River	Bingham	1, 032	--	80	--	Tr.	80	--	808	Do.

[1] Lacks gold.
[2] Platinum present.

granite. Anderson thought that the placers were not sufficiently rich in monazite to be worked for that mineral alone but that it might be possible to recover monazite as a byproduct of gold mining, although none had been saved in the district.

Orofino Creek at localities north and south of Pierce has been cited for monazite (Hubbard, 1955, fig.). These localities are probably among the ones listed by Day and Richards (1906b, p. 1200–1201), Savage (1960, fig. 1), and Shannon (1926, p. 414) for the Pierce district.

Monazite placers in the valley of Musselshell Creek, a tributary to Lolo Creek in Clearwater County (by some referred to as placers 10 miles from Weippe) were described by Schrader (1910, p. 185–188), and have been cited several times since the original description (Schrader and others, 1917, p. 119; DeMent and Dake, 1948, p. 15; Dake, 1955, p. 56; Hubbard, 1955, p. 55); they have not been mined. According to Schrader the valley floor of Musselshell Creek is 250 feet wide and is covered with a sheet of Recent alluvium that averages about 8 feet in thickness. Muck, sand, and clay make up the upper 3–4 feet of alluvium and overlie a layer of gravel about 4 feet thick which rests on granite. Along the sides of the valley are some old gravel terraces as much as 11 feet thick. Both the old and the Recent gravel deposits are low-grade gold placers. Monazite is also present in both kinds of deposits, but it seems to be more plentiful in the terrace deposits. Other heavy minerals associated with the monazite are ilmenite, magnetite, garnet, and zircon.

The monazite from the Musselshell Creek placers is fine grained, subangular, and splendent. It is derived from the granitic rocks of the Idaho batholith. Eleven concentrates prepared from the placer gravel by Schrader (1910) were found to contain from 7.5 to 45 percent of monazite and had a mean tenor of 29 percent of monazite. Monazite was reputed to be less plentiful in the gravel of Musselshell Creek than it is in the alluvium in the Pierce district (Anderson, A. L., 1930, p. 61), but by 1955 the tenors on Musselshell Creek were described as "rich" and "of commercial significance" (Hubbard, 1955, p. 55). The monazite, however, is low in thorium.

Analyses of four nonmagnetic fractions from concentrates from Musselshell Creek were made by R. C. Wells (Sterrett, 1911, p. 902–903) who reported the following percentages of thorium oxide in concentrates having 8.7–15.5 percent of P_2O_5:

	A	B	C	D
ThO_2	1. 20	1. 15	1. 85	0. 88
P_2O_5	10. 9	8. 9	15. 5	8. 7

Recalculated to pure monazite the analyses indicate that the monazite from Musselshell Creek contains about 3.3 percent of ThO_2. Schrader (1910, p. 188) commented that a large number of samples of sand from northern Idaho had been concentrated to about 90 percent of monazite and that the concentrates were analyzed by the Welsbach Light Co. and were found to contain about 3 percent of ThO_2.

Streams in Nez Perce County were shown by Day (1905a, p. 9) and by Day and Richards (1906a, p. 153; 1906b, p. 1200–1201) to contain detrital monazite. They reported a trace of monazite in placer concentrates from the Clearwater River at Lewiston and 46 pounds per short ton in black sand questionably derived from the Salmon River (table 44). Sand from the Snake River between the mouth of the Clearwater River and Asotin, Wash., is monazite bearing (Staley, 1952, p. 308). A concentrate taken from the Snake River and consisting of as much as 95 percent of monazite was reported to have 63 percent of RE_2O_3, 2 percent of ThO_2, 24.4 percent of P_2O_5, and 3.9 percent of ZrO_2 with the remainder not listed (Staley, 1952, p. 308).

IDAHO COUNTY

Detrital monazite occurs in at least 12 areas in Idaho County. Most of them are in the central part of the county, but an undescribed deposit has been reported from Eldorado Creek, a tributary to Lolo Creek about 28 miles east of Greer in northern Idaho County.

The Elk City gold placers have yielded concentrates containing as much as 800 pounds of monazite per short ton of concentrate (table 43), but the tenor of the raw sand was not described (Day and Richards, 1906b, p. 1196–1199). Columbite and fergusonite were identified in monazite-bearing concentrates from the Elk City district by Thomson and Ballard (1924, p. 48). Gold placers in Buffalo Gulch near Elk City were said to contain ilmenite, gold, zircon, cassiterite, and monazite (Eng. and Mining Jour., 1950a), and a concentrate from the property of the Tyee Mining Co. near Elk City was described by Staley and Browning (1949, p. 4) as consisting of abundant ilmenite and sparse monazite. The Elk City district was sampled for monazite in the 1950's by the U.S. Bureau of Mines. In a summary of the geology and heavy minerals of the placers in the Elk City district, R. R. Reid (1960) reported that the average tenor of 15 samples of stream gravels was as follows:

	Tenor (lb per cu yd)
Allanite	0. 2
Monazite	. 15
Rutile	. 07
Brookite	. 1
Sphene	. 1
Zircon	. 25
Ilmenite	6. 9
Magnetite	16. 8

Traces of brannerite, euxenite, and columbite were found. According to R. R. Reid the volume of stream gravel in the Elk City district is 55 million cubic yards of which 25 million has already been mined for gold. Minable deposits of stream gravel are present in wide low-gradient parts of the valleys.

Monazite-bearing basin deposits of Tertiary age cap some ridges and benches in the Elk City district (Reid, R .R., 1960). They crop out over an area of about 18 square miles and were said by Reid to have an average thickness greater than 60 feet and a possible volume of at least 100 million cubic yards. Four small grab samples from these Tertiary rocks were found by Reid to contain an average per cubic yard of 1.6 pounds of monazite, 0.3 pound of rutile, and 0.3 pound of zircon.

Baker Gulch on the Crooked River and the river itself southwest of Elk City contain placer monazite as shown on table 43 (Day and Richards, 1906b, p. 1198–1199; Hubbard, 1955, fig.).

The South Fork of the Clearwater River in Idaho County was the source of a concentrate containing 55–60 percent of monazite (Staley, 1952, p. 306). An analysis of the concentrate was said by Staley to have disclosed 37.1 percent of RE_2O_3, 1.6 percent of ThO_2, 15.2 percent of P_2O_5, and 23 percent of ZrO_2. The monazite alone may have about 2.7 percent of ThO_2.

Detrital monazite has been found along four northern tributaries to the Salmon River in the western part of Idaho County. It is present in Crooked Creek at Dixie (Savage, 1960, fig. 1), in Penmans Fork of Big Creek (Day and Richards, 1906b, p. 1198–1199), in Lake Creek (Capps, 1940, p. 27; Kauffman and Baber, 1956, p. 7; Eilertsen and Lamb, 1956, p. 12), and in Grouse Creek in the Florence mining district (Reed, 1939, p. 27, fig. 4; Eilertsen and Lamb, 1956, p. 11). Little is known about any of these occurrences except that they are all uneconomic sources for monazite. Day and Richards stated that a placer concentrate from Penmans Fork contained 528 pounds of monazite per short ton, and material from an undescribed locality in the Florence district showed a trace of monazite. The Lake Creek and Grouse Creek gold placers were described briefly by Capps (1940, p. 27) of the U.S. Geological Survey. They were sampled by the U.S. Bureau of Mines in the 1950's. Reed (1939) of the U.S. Geological Survey showed that only 1 concentrate out of 37 from the Florence gold mining district contained monazite. It came from Grouse Creek and had 50–60 percent of monazite, 35–45 percent of zircon and apatite, 4 percent of ilmenite and garnet, and 1 percent of magnetite. In Reed's opinion the Grouse Creek monazite had no commercial value under the economic conditions of 1939.

Southern tributaries to the Salmon River in the western part of Idaho County have been widely explored for monazite, and some of the gold placers excited interest in the early 1950's as possible commercial sources for monazite (Eng. and Mining Jour. 1950b; Hill, W. H., 1951, p. 14). The first descriptions of monazite in these streams were given by Day and Richards (1906b, p. 1198–1199), who showed that it was a conspicuous component of placer concentrates from the Marshall Lake district and was present in small amounts at Syringa and in the Camp Howard district (table 43). East and south of Burgdorf the gold placers in the basin of Secesh Creek were shown by Capps (1940, p. 27–37) to be variably monazite bearing, and the abundance of the monazite was related to the bedrock geology. Farther east, in the Warren district, monazite was observed in the gold placers around Warren about 1904 (Bell, 1904, p. 224) and near Resort (table 43) by 1906 (Day and Richards, 1906b, p. 1198–1199; Bell, 1915, p. 28). The Warren district was thought by Schrader, Stone, and Sanford (1917, p. 119) to have the best monazite placers in Idaho County. In 1951 an effort seems to have been made to recover monazite from the Canyon Placer near Warren (Hill, W. H., 1951, p. 14; Hubbard, 1955, p. 55) and the meadows of Ruby Creek near Burgdorf (Hubbard, 1955, p. 55). During the early 1950's monazite deposits along southern tributaries to the Salmon River in western Idaho County were explored by the U.S. Bureau of Mines. Results of investigations in the Kelly Meadows near Burgdorf, Secesh Meadows on Secesh Creek, and the Warren Meadows in the Warren district were not published (Eilertsen and Lamb, 1956, p. 11). The most complete accounts of the geology of these placers were the reports by Capps (1940) on the Secesh Creek area and by Reed (1937) on the Warren mining district.

According to Capps (1940), the basin of Secesh Creek is mainly underlain by epodite-bearing quartz monzonite and related rocks of the Idaho batholith with subordinate areas of gneiss, quartzite, and schist, all intruded by granite. Among the metamorphic rocks are quartz-sillimanite schist, biotite-sillimanite-garnet gneiss, and diopside-clinozoisite gneiss. These rocks are identical to those described earlier by Reed (1937) in the Warren mining district. A few small blocks of tilted and downfaulted Tertiary sedimentary rocks are preserved in structural depressions. Unconformably overlying the crystalline rocks and Tertiary sediments are extensive deposits of unconsolidated sedimentary materials of Pleistocene and Recent age including moraines from at least two stages of glaciation, terrace gravel of two or three ages, and Recent stream deposits. Locally these materials have been widely distributed and redeposited by placer mining operations. The crystalline rocks in the Secesh Creek area are deeply weathered and covered by the products of disintegration and decomposition except where these have been removed by glaciation and other forms of erosion (Capps, 1940, p. 7). Valleys in the upper part of Secesh Creek and its tributaries consist typically of alternate reaches of broad, open meadows separated by narrow canyons resulting from the dislocation of the channels of the streams during glaciation.

Pre-Wisconsin moraine and terrace gravel near the mouth of Three Mile Creek about 2.4 miles north of Burgdorf contain traces of monazite and zircon, abundant corundum, small amounts of garnet, hematite, ilmenite, and limonite, and virtually no magnetite (Capps, 1940, p. 32). The narrow part of Ruby Creek near Burgdorf is especially rich in monazite (Capps, 1940, p. 34, 37; Staley and Browning, 1949, p. 4), which occurs in sluice-box concentrates made from pre-Wisconsin moraine gravel, Wisconsin moraine gravel, and Recent gravel (table 44). Monazite and cinnabar are described as being in considerable quantity.

TABLE 44.—*Mineralogical composition of sluice-box concentrates from placer materials along Ruby Creek, Idaho County, Idaho*

[Modified from Capps (1940, p. 34). Symbols used: P, present; Ab, absent]

	Pre-Wisconsin moraine	Wisconsin moraine and underlying pre-Wisconsin gravel	Recent gravel of Ruby Creek
Quartz	Ab	P	P
Magnetite	P	P	Ab
Ilmenite	P	P	P
Garnet	P	P	P
Zircon	P	P	P
Monazite	P	P	P
Cinnabar	P	P	P
Rutile	P	Ab	Ab
Feldspar	P	P	P
Augite	P	Ab	Ab
Hornblende	P	Ab	Ab
Andalusite	P	Ab	Ab
Muscovite	P	Ab	Ab
Gold	P	P	P

Partial analyses of concentrates that have possibly 80–85 percent of monazite from Ruby Creek near Burgdorf were reported to contain 51.5 percent of RE_2O_3, 3.2 percent of ThO_2, 20.6 percent of P_2O_5, and 10.1 percent of ZrO_2 (Staley, 1952, p. 308). Monazite from Secesh Creek was analyzed by the U.S. Bureau of Mines and found to contain 5.75 percent of ThO_2 and 0.25 percent of U_3O_8 (Kauffman and Baber, 1956, p. 6).

The Warren gold placer district, described in detail by Reed (1937), is underlain in the northwest by Precambrian gneiss, quartzite, and schist. Elsewhere the rocks are mainly epidote-bearing biotite-muscovite-quartz monzonite and related rocks of the Idaho batholith. Biotite-sillimanite-garnet gneiss and muscovitic or dense quartzite are the most common metamorphic rocks. At their contacts with the batholithic rocks, they are widely impregnated with granitic material and one rock grades into another. Unconsolidated sediments of several ages and origins occupy large parts of the Warren district. They include Tertiary gravel, pre-Wisconsin gravel, Wisconsin glacial moraine, and Recent alluvium. There are placer gravels in bench, hillside, and high-meadow deposits, and in the Recent alluvium there are meadow and gulch deposits. The bench, hillside, and gulch deposits have been largely worked out for gold, and most of the meadow deposits have also been mined. W. H. Hill (1951, p. 14) estimated, however, that there are 40 million cubic yards of tailings 10–35 feet deep that have been left from gold mining in the 1930's and 1940's but that are rich enough in monazite to be dredged as monazite placers.

According to Reed (1937, p. 31–33), the concentrates from the various auriferous sedimentary materials in the Warren district are mineralogically similar. In Reed's estimated order of decreasing abundance, the most abundant minerals are monazite, garnet, magnetite, and zircon. Common minerals are limonite, gold, and epodite, and uncommon minerals are corundum, rutile, apatite, and xenotime. Scarce minerals are tourmaline, hornblende, pyrite, uraninite, and sillimanite. Inasmuch as only nine concentrates were examined by Reed, he cautioned that the estimated order of abundance may not be significant regionally for the uncommon and scarce minerals.

The abundant and common accessory minerals are a voluminous part of the sand-sized fraction of the alluvium in the Warren area; within a few hours of the commencement of a placer operation following a clean-up, the riffles filled with heavy minerals, and the recovery of gold was impaired (Reed, 1937, p. 30). Much of the heavy sand, about 45 percent according to W. H. Hill (1951, p. 14) and as much as 50 percent in a few samples according to Reed, was monazite. The monazite grains were said to be whole individual crystals with roughened faces and rounded edges (Reed, 1937, p. 32). They are smaller than many of the other heavy minerals. Most grains will pass through a 28-mesh sieve but will be retained on a 300-mesh sieve. Ordinary riffle sand screened to 20-mesh on a gold dredge in Warren Meadows, but not otherwise concentrated, was analyzed by R. C. Wells and found to contain 1.7 percent of ThO_2, and sand passing a 60-mesh sieve contained about 2.8 percent of ThO_2. Thus, the monazite content of the Warren Meadows heavy sand can be significantly upgraded merely by sieving.

An analysis of monazite from Warren Meadows made by the U.S. Bureau of Mines showed 3.96 percent of ThO_2 and 0.17 percent of U_3O_8 (Kauffman and Baber, 1956, p. 6), and an analysis by the U.S. Geological Survey indicated 3.7 percent of ThO_2 and 0.16 percent of U_3O_8 (Gottfried and others, 1959, p. 21).

VALLEY COUNTY

Detrital monazite was first reported in Valley County at Lardo (table 43) by Day and Richards (1906b, p. 1196–1197), but it was not until the late 1940's and early 1950's that any was mined. In 1949 a plant was constructed at McCall to separate monazite, ilmenite, magnetite, and garnet from black sands recovered during gold mining (Staley and Browning, 1949, p. 2; Mining Cong. Jour., 1949; Eng. and Mining Jour., 1949). Only the monazite was marketed; the other minerals were stockpiled. Beginning in 1950 several monazite deposits were explored by the U.S. Bureau of Mines, and by January 1951 private interests had begun to produce monazite by dredging Big Creek in the Cascade or Long Valley placer district (Lamb 1955a; Eilertsen and Lamb, 1956, p. 25). Production continued on Big Creek until August 1955. During 1954 construction was started by Porter Brothers, Inc., on a dredge in monazite-euxenite placers in the Bear Valley area about 30 miles southeast of the Cascade district (Crawford, 1958a, p. 1158). Byproduct monazite was produced there from June 1956 until at least 1958 (Crawford, 1958b, p. 1125; Lewis, 1959, p. 1). Commercial monazite from the Cascade or Long Valley district was said by Kremers (1958, p. 2) to contain 63 percent of RE_2O_3 and 3 percent of ThO_2.

The most northerly of the monazite placer deposits in Valley County is at Squaw Meadows just across the county line from the placers on Secesh Creek. Exploration was conducted by the U.S. Bureau of Mines at Squaw Meadows during the early 1950's.

The Cascade or Long Valley placer district in Valley County was said to be the largest monazite placer district in Idaho (Staley, 1952, p. 309–310). It includes several monazite-bearing eastern tributaries to the North Fork of the Payette River near Cascade. The North Fork rises in the Payette Lakes north of McCall and flows southward through a conspicuous depression, formed by late Tertiary and Pleistocene faulting, known as Long Valley (Kline and Carlson, 1954, p. 10; Mackin and Schmidt, 1956, p. 376). As described by J. H. Mackin (Kline and Carlson, 1954, p. 10) Long Valley is a basin 40 miles long and 2–8 miles wide bordered by high mountains which rise steeply on the west and less precipitously on the east. The floor of the valley is covered by a thick sequence of monazite-bearing alluvium, possibly in part lacustrine, brought in during at least two periods of deposition by streams flowing mainly westward off the granitic rocks of the Idaho batholith. Sediments formed in the fault trough during the earlier of the two periods of deposition were tilted westward by later faulting and are exposed along the east side of Long Valley. In the western part of the valley the earlier deposited alluvium was buried under the thick later formed sequence of sediments. Thus, the valley fill consists of a composite wedge of monazite-bearing sediment that thickens westward and may be as much as several thousand feet thick in the western part of Long

Valley. The tenors of the deep parts of these sediments are not known.

The North Fork of the Payette River flows along the west side of Long Valley, and its eastern tributaries reach it by crossing the alluvium of the valley floor. Between the Payette Lakes and Donnelly only trace amounts of monazite have been found in the bed of the North Fork, and the stream gravel was said to consist principally of fragments of metamorphic rocks distinctly different in provenance from the granitic gravel in the monazite-rich eastern tributaries to the North Fork in the Cascade district south of Donnelly (Kline and Carlson, 1954, p. 10; Hubbard, 1955, fig.).

West of Donnelly in an area around West Mountain where granitic rocks of the Idaho batholith are exposed on the west side of Long Valley, monazite was reported to occur in placer deposits, which were explored by the U.S. Bureau of Mines in the early 1950's (Eilertsen and Lamb, 1956, p. 11).

About 4 miles south of Donnelly the Gold Fork enters the North Fork of the Payette River from the east. The stream is underlain by granitic rocks of the Idaho batholith. The Gold Fork was explored for monazite in 1951 by the U.S. Bureau of Mines and the U.S. Bureau of Reclamation. Although a report of the preliminary work was never published (Eilertsen and Lamb, 1956, p. 11), the placer was reexamined for ilmenite and other black-sand minerals in 1956, and a summary of the combined results of exploration in 1951 and 1956 was presented by Storch (1958a). These studies showed that Gold Fork occupies a narrow valley except for a reach about 6 miles long upstream from its confluence with the North Fork. There the valley floor is 1,000–4,000 feet wide, being widest at its downstream end, and Gold Fork, is entrenched 10–50 feet in gravel deposits. Parts of this area are covered by the impounded waters of the Cascade Reservoir. Thirty-one holes were drilled in the wide part of the Gold Fork valley to depths that ranged from 16 to 140 feet. Only three holes reached bedrock. The distribution of black sand was found to be erratic, but the greatest amount was generally along the south side of the present channel of Gold Fork. A wide variety of minerals are present, as shown by the complete mineralogical analyses of concentrates from four holes (table 45).

Ilmenite is the dominant mineral and is followed in abundance by garnet, magnetite, and sphene. The suite is little weathered, and the ilmenite is not enriched in titanium oxides. Monazite, a minor component of the concentrates from Gold Fork, was shown to contain 4.84 percent of ThO_2 and 0.18 percent of U_3O_8 (Kauffman and Baber, 1956, p. 6). The weighted tenor in monazite in 44 composite samples of sediments from the drill holes was reported by Storch (1958a, p. 9).

TABLE 45 —*Mineralogical composition, in percent, of black sands from the Gold Fork placer, Valley County, Idaho*

[Modified from Storch (1958, p. 14). Symbols used: SA, small amount; --, absent]

	Drill holes			
	G-13	GF-3	GF-10	GF-11
Ilmenite	45. 7	55	48	40
Garnet	27. 4	21	18	15
Magnetite	1. 9	2	24	26
Sphene	5. 7	7	3	3
Quartz	8. 0	SA	SA	SA
Epidote	3. 2	Trace	1	Trace
Kyanite	1. 4	--	--	--
Ferromagnesian minerals	1. 7	Trace	Trace	Trace
Zircon	1. 1	1	1	1
Monazite	2. 0	2	1	1
Xenotime	. 3	--	Trace	Trace
Allanite	Trace	Trace	Trace	Trace
Rutile	--	Trace	Trace	<. 5
Topaz	--	Trace	Trace	Trace
Columbite	--	Trace	--	--
Feldspar	--	Trace	Trace	Trace
Apatite	--	--	Trace	Trace
Radioactive opaque minerals	--	Trace	Trace	Trace

Weighted tenor, in pounds per cubic yard, of composite samples from drill holes in the valley of Gold Fork

	Minimum	Maximum	Average of 44 samples
Monazite	Trace	0. 81	0. 37
Ilmenite	1. 37	26. 20	9. 27
Magnetite	Trace	20. 25	4. 69
Garnet	. 65	11. 54	2. 91
Zircon	Trace	. 68	. 27

The Beaver Creek placer area is in the north end of the Cascade Valley in the Long Valley placer district (Storch and Robertson, 1954, p. 6). The placers extend about 4 miles northward along East Fork Creek and Beaver Creek, which are eastern tributaries to the North Fork of the Payette River and which drain from areas underlain by granitic rocks at the western edge of the Idaho batholith. During 1952 the U.S. Bureau of Mines drilled 16 holes in flood-plain deposits along East Fork Creek and Beaver Creek and estimated the monazite content of the sediments.

Tenor, in pounds per cubic yard, of stream deposits from East Fork and Beaver Creeks

	Minimum	Maximum	Average of 16 samples
Monazite	0.1	0.54	0.28
Ilmenite	2.53	27.39	9.91
Magnetite	.07	1.57	.58
Garnet	Trace	.24	.04
Zircon	.01	.21	.06

Monazite from the Beaver Creek placer was analyzed by the U.S. Bureau of Mines and found to contain 3.82 percent of ThO_2 and 0.35 percent of U_3O_8 (Storch and Robertson, 1954, p. 13). The Beaver Creek placer area is not an economic source for monazite.

The Big Creek area is in the Long Valley district near Cascade. It consists of placers on parts of Big Creek, including Scott Valley and the adjacent Horsethief Creek, and deposits on Pearsol, Corral, and Clear Creeks.

Scott Valley and Horsethief Creek are about 7 miles east of Cascade. Scott Valley is a high mountain basin drained by Big Creek. It is about 5 miles long, 300–3,000 feet wide, and is carved in granitic rocks that form part of the west side of the Idaho batholith. Horsethief Creek is a tributary to Big Creek. The placer on Horsethief Creek lies half a mile south of Scott Valley. It is a basin about 6,000 feet long, as much as 2,000 feet wide, and occupies about one-fourth as much area as Scott Valley.

Scott Valley and the Horsethief Creek basin seem to be in structural depressions controlled by faults. On its west side Scott Valley is bordered by fine-grained hard granite very resistant to weathering and on its east side it is bordered by soft, easily weathered coarse-grained granite. Renewed action along the faults was thought by Kline, Carlson, and Storch (1951a, p. 9) to have intermittently and partly sealed off Big Creek and Horsethief Creek with the result that lakes were formed and thick sequences of sediments were deposited in them. These lacustrine sediments consist of clay, sand, and fine-grained gravel derived from the granite. They were sampled by the U.S. Bureau of Mines in 1950 when 16 holes were drilled in Scott Valley and three were drilled in the Horsethief Creek basin (Kline and others, 1951a, p. 4). The holes in Scott Valley ranged in depth from 5 to 68 feet and those in the Horsethief basin, from 10 to 59 feet.

Heavy minerals in the sediments at Scott Valley and Horsethief Creek basin were found to be concentrated above layers of clay which served as false bedrock. The following mineralogical composition of composite concentrates from the two placer areas was analyzed by the U.S. Bureau of Mines:

Mineralogical composition, in percent, of composite concentrates from Scott Valley and Horsethief Creek, Valley County, Idaho

[Modified from analyses by U.S. Bur. Mines (Kline and others, 1951a, p. 10)]

	Scott Valley	*Horsethief Creek*
Ilmenite	73.0	50.9
Quartz	11.0	20.9
Garnet	5.0	3.0
Monazite	3.8	11.5
Zircon	1.8	.8
Xenotime	.2	.2
Epidote	<.1	2.1
Rutile	------	2.6
Magnetite	<.1	2.0
Pyrite	------	3.0
Amphibole, pyroxene, mica	.8	1.5
Opaque minerals	2.5	-------

The few holes in the Horsethief Creek basin indicate that this placer may be somewhat richer in monazite and leaner in total heavy minerals than the Scott Valley deposit (Kline and others, 1951a, p. 17).

Tenor, in pounds per cubic yard, of deposits in Scott Valley and Horsethief Creek basin

	Scott Valley			Horsethief Creek basin		
	Minimum	Maximum	Average of 15 samples [1]	Minimum	Maximum	Average of 3 samples
Monazite	0.21	1.60	0.83	0.61	1.68	1.30
Ilmenite	2.15	15.67	9.53	1.37	3.75	2.65
Magnetite	.17	6.80	1.01	.15	.42	.31
Garnet	.47	4.15	1.90	.09	.47	.28
Zircon	.38	1.33	.65	.08	.55	.32

[1] Calculation of tenor of one hole not included in original report.

The results of analyses by the U.S. Bureau of Mines showed an average of 4.11 percent of ThO_2 and 0.17 percent of U_3O_8 for three samples of monazite from Scott Valley and 4.74 percent of ThO_2 and 0.10 percent of U_3O_8 in one sample of monazite from the Horsethief Creek basin (Kline and others, 1951a, p. 19). The Scott Valley and Horsethief Creek deposits apparently were not mined during the early 1950's when monazite was recovered from placers farther downstream where Big Creek flows across Long Valley.

Big Creek emerges from Scott Valley in a steep, narrow drop where it cuts its way for about 2 miles through granitic mountains to enter the east side of

Long Valley. The stream flows across Long Valley to its confluence with the North Fork of the Payette River. Where Big Creek crosses Long Valley the stream has formed a monazite-bearing meander plain 1,200–2,500 feet wide which is bordered by sand and gravel benches 10–20 feet high (Kline and others, 1951b, p. 5). This part of Big Creek was farmed and had no prior history of mining at the time it was explored for monazite in 1950 by the U.S. Bureau of Mines.

The gravel, sand, and silt underlying the Big Creek meander plain was explored with 39 holes ranging in depth from 30 to 110 feet. To the maximum depth drilled the sediments were found to be composed of granitic debris. The gravel is small; few fragments are larger than 3 inches across. Well-sorted pebble layers having particles mostly about a quarter of an inch in diameter and scant clay or silt contain the greatest concentrations of heavy minerals. Commonly these layers rest on false bedrock consisting of a bed of clay. Concentrations of heavy minerals were also found in the sediments under the low terraces on each side of the meander plain.

The average mineralogical composition of the concentrates was reported to be the following (Kline and others, 1951b, p. 10):

	Percent
Ilmenite	65.4
Monazite	8.0
Garnet	6.5
Zircon	2.5
Magnetite	1.0
Pyroxene, amphibole, biotite	4.5
Pyrite	.3
Quartz, feldspar	11.8

Analyses made by the U.S. Bureau of Mines on four samples of monazite from Big Creek were reported as follows (Kline, Carlson, and Storch, 1951b, p. 20):

	Percent ThO_2	*Percent* U_3O_8
BCD–11	4.12	0.139
14	4.23	.132
31	4.18	.123
32	4.26	.120
Average	4.19	.13

Field estimates of the amount of monazite in the sediments from the 39 drill holes ranged from 0.23 to 3.37 pounds of monazite per cubic yard and averaged 1.68 pounds per cubic yard. The field estimates were stated by Kline and others (1951b, p. 17) to be less accurate than the laboratory estimates, which were used to calculate ore reserves. Seemingly, the field estimates of monazite are somewhat too great, but the difference was not reported for all samples. In seven comparisons the field estimates were shown to be 10–40 percent higher than the laboratory estimates. Field estimates for other heavy minerals were reported by Kline and others (1951b, p. 17).

Tenor, in pounds per cubic yard, of sediments from Big Creek
[Based on field estimates]

	Minimum	Maximum	Average of 32 samples
Ilmenite	4.16	27.52	14.08
Magnetite	Trace	.81	.17
Garnet	.16	3.31	1.58
Zircon	.23	1.52	.66

The results of the exploration indicated that the area contains comparatively large volumes of minable monazite-bearing gravel (Kline and others, 1951b, p. 5; Cummins, 1952, p. 169; Hubbard, 1955, p. 55).

In 1951, private companies commenced to dredge for monazite in the Big Creek meander plain in Long Valley, and the operation continued until August 1955 after which date contracts for the monazite could not be obtained and mining ceased (Eng. and Mining Jour., 1950c; Mining Eng., 1951; Kauffman and Baber, 1956, p. 11; Crawford, 1958a, p. 1157-1158). Estimates of the output have not been given. After the close of mining, the deposit was said to have yielded 80,000 short tons of ilmenite as a stockpiled byproduct and to contain a reserve of 400,000 short tons of ilmenite (Kauffman and Baber, 1956, p. 9). If the field estimate cited above for the average tenor in monazite is reduced somewhat to accomodate the indicated overestimate and is called 1.4 pounds of monazite per cubic yard and if this is compared to the field estimate of the average tenor in ilmenite (about 14 pounds per cubic yard), then the inference can be made that the Big Creek placer may have produced about 8,000 short tons of monazite and has reserves of perhaps 40,000 short tons of monazite. Probable low recovery of monazite compared to ilmenite may somewhat reduce this estimated output.

Pearsol Creek is a small stream about 4 miles long that rises in the foothills immediately east of Long Valley. Monazite placers occur in the Long Valley part of Pearsol Creek north of and contiguous with the monazite deposits in the Long Valley part of Big Creek. The Pearsol Creek placers are about 1½ miles south of the town of Cascade. A block of ground about 2 miles long from north to south and 1½ miles wide in the Pearsol Creek placer area was explored with 65 holes drilled by the U.S. Bureau of Mines in 1951 (Kline and Carlson, 1954, p. 5). The geology of the deposit is virtually the same as that of the Big

Creek deposit, and the southern part of the Pearsol Creek placer nearest to Big Creek has the best tenor in monazite. Although minable tenors in monazite were detected to a depth as great as 120 feet in one hole, in most holes the best tenors were at depths of 15–55 feet.

A composite concentrate from one drill hole in the Pearsol Creek placer was found to contain about one-tenth as much monazite as ilmenite (Kline and Carlson, 1954, p. 12):

	Percent		*Percent*
Ilmenite	80. 5	Garnet	1. 6
Altered ilmenite	1. 0	Quartz	5. 9
Magnetite	. 7	Zircon	. 1
Epidote	. 2	Xenotime	. 1
Pyroxene, amphibole, biotite	. 2	Monazite	8. 4

Minor amounts of allanite and radioactive opaque minerals are present in concentrates from the Pearsol Creek placer. Inclusions of a fergusonitelike mineral were observed in some grains of monazite, and a small amount of very fine grained gold was found in a few concentrates.

The tenors of the sediments in about one-third of the southern part of the Pearsol Creek placer are similar to those in the Big Creek deposit, elsewhere they are less, and in the north half of the area magnetite makes up 10–30 percent of the concentrate (Kline and Carlson, 1954, p. 11, 18, 19). Sediments sampled in the 65 drill holes contained 1.94–69.01 pounds of concentrates per cubic yard with an average of 14.7 pounds per cubic yard. Monazite made up 1.4–18.3 percent of the concentrate and averaged 6.9 percent by field estimate. Somewhat less monazite was indicated by the results of laboratory examination: by chemical analysis the range was 1.6–12.7 percent, with an average of 6.3 percent, and by radiometric analysis the range was from 2.0 to 12.8 percent, with an average of 6.7 percent. The tenor determined by chemical analysis was the most accurate. The richest part of the Pearsol Creek placer was said by Kline and Carlson (1954, p. 8) to be along the east side of Long Valley just north of the Big Creek deposit. Monazite from the Pearsol Creek placer was analyzed by the U.S. Bureau of Mines and found to contain 4.4 percent of ThO_2 and 0.2 percent of U_3O_8 (Kline and Carlson, 1954, p. 21–22).

Corral Creek is about 2 miles south of the Big Creek placer area and 5 miles southeast of Cascade, Valley County. The stream is 4 miles long and flows westward into Long Valley from the foothills to the east. A north-trending area 2 miles long and 1½ miles wide along the part of Corral Creek in Long Valley was drilled for monazite in 1951 by the U.S. Bureau of Mines (Kline and others, 1955, p. 5). Sixty-one holes from 20 to 123 feet deep were sunk. Samples of alluvium contained from 0.29 to 14.94 pounds of concentrate per cubic yard and averaged 6.33 pounds. By field estimate from 4.2 to 38.3 percent of the concentrate was monazite, the average being 20.5 percent (Kline and others, 1955, p. 16–20). Somewhat less monazite was indicated by laboratory analyses of samples from 59 out of the 61 holes, of which the chemical determinations were regarded by the Bureau as the more accurate: the range was from 4.2 to 33.9 percent with an average of 18.7 percent by chemical analysis and from 4.8 to 38.2 percent with an average of 18.6 percent by radiometric determinations.

The following mineralogical composition, in percent, of concentrates from three drill holes in the Corral Creek placer area was reported (Kline and others, 1955, p. 11):

	CO-6	CO-16	CO-50
Monazite	22. 5	19. 6	34. 2
Magnetite	1. 4	8. 2	. 2
Ilmenite	59. 6	60. 1	60. 0
Garnet	Trace	Trace	Trace
Zircon	1. 0	. 5	. 4
Epidote	. 8	. 4	-------
Xenotime	. 1	. 1	Trace
Euxenite, samarskite	Trace	-------	-------
Quartz	12. 5	9. 0	4. 5
Pyroxene, amphibole, biotite	. 3	. 4	-------

Monazite from the Corral Creek placer area was analyzed by the U.S. Bureau of Mines and found to contain 4.39 percent ThO_2 and 0.10 percent U_3O_8 (Kline and others, 1955, p. 18).

Geologically the Corral Creek placer resembles the Big Creek placer. The central one-third of the area drilled, which is on the Big Creek side of Corral Creek, was said to be the richest part of the deposit (Kline and others, 1955, p. 7).

Clear Creek crosses Long Valley from the east about 8 miles southeast of Cascade. The stream was explored for monazite in the early 1950's by the U.S. Bureau of Mines (Eilertsen and Lamb, 1956, p. 11). Monazite from the Clear Creek placer was said to contain 4.13 percent ThO_2 and 0.12 percent U_3O_8 (Kauffman and Baber, 1956, p. 6).

The Stolle Meadows, a mountain valley on the South Fork of the Salmon River, are about 20 miles northeast of, and outside of, the Cascade or Long Valley placer district. They were explored for monazite during the early 1950's by the U.S. Bureau of Mines (Eilertsen and Lamb, 1956, p.11; Kauffman and

Baber, 1956, p. 7). Similarly, Peace Valley on a tributary to the Middle Fork of the Payette River, about 15 miles southeast of, and outside of, the Cascade or Long Valley placer district, was explored for monazite by the Bureau in the early 1950's (Eilertsen and Lamb, 1956, p. 11).

A large valley on the Deadwood River, a northern tributary to the South Fork of the Payette River in the south-central part of the Idaho batholith in Valley County, was drilled by the U.S. Bureau of Mines in 1956 and appraised as having no economic value as a source for monazite or ilmenite (Storch, 1958b, p. 9). Ten holes ranging in depth from 6 to 40 feet were sunk, and samples showed that the sediments contained less than 0.1 pound of monazite and only 3.3 pounds of ilmenite per cubic yard.

The Deadwood River deposit in Valley County is 8 miles long and about 1,000 feet wide, locally expanding in width to more than 3,000 feet. It is floored with glacial deposits and alluvium on granite. Only the downstream one-third of the length of the valley was explored. None of the drill holes reached bedrock; hence, the thickness of the fill is not known. Apparently an early sequence of sediments was deposited in the valley and later disturbed by glacial erosion. The present sequence of sediments has virtually the same concentration of heavy minerals as the rocks of the valley walls. Field estimates of the five main heavy minerals were reported by Storch (1958b, p. 9).

Weighted tenor, in pounds per cubic yard, of concentrates from 10 drill holes in the Deadwood River deposit

	Minimum	Maximum	Arithmetic average
Monazite	Trace	0.28	0.08
Ilmenite	0.43	10.78	3.28
Magnetite	.36	13.55	4.57
Garnet	.08	1.57	.20
Zircon	.03	.20	.09

The complete mineralogical composition of concentrates from four drill holes in the Deadwood River alluvium is given in table 46.

A few miles east of the monazite occurrence at Deadwood River, several headwater tributaries to the Middle Fork of the Salmon River in Valley County were reported to be monazite bearing. Elk Creek and the White Hawk basin were explored for monazite by the U.S. Bureau of Mines (Kauffman and Baber, 1956, p. 7).

A very large monazite-euxenite placer was discovered by the U.S. Bureau of Mines on Bear Valley Creek in Valley County during exploration between 1950 and 1952, and dredging of the deposit was begun

TABLE 46—*Mineralogical composition, in percent, of concentrates from drill holes in Deadwood River alluvium, Valley County, Idaho*

[Modified from analyses by U.S. Bur. Mines (in Storch, 1958, p. 13). Symbols used: SA, small amount; --, absent]

	DW-1	DW-2	DW-5	DW-9
Ilmenite	34.0	10.0	14.0	33.0
Magnetite	49.0	74.0	61.0	22.0
Garnet	SA	SA	--	SA
Titaniferous magnetite	3.0	3.0	4.0	3.0
Sphene	.5	1.0	--	5.0
Ferromagnesian minerals.	SA	SA	3.0	Trace
Gahnite	Trace	--	--	--
Rutile	<.5	<.5	Trace	<.5
Ilmenorutile	Trace	Trace	Trace	--
Zircon	.5	.5	<.5	2.0
Epidote	--	Trace	Trace	Trace
Hematite	Trace	Trace	Trace	Trace
Allanite	Trace	Trace	Trace	SA
Apatite	Trace	Trace	Trace	<.5
Pyrite	Trace	Trace	Trace	Trace
Xenotime	Trace	Trace	Trace	Trace
Cyrtolite	--	--	Trace	--
Columbite	--	--	Trace	Trace
Monazite	Trace	<.5	<.5	<.5
Radioactive opaque minerals	Trace	<.5	Trace	Trace

by Porter Brothers Corp. in 1955 and continued after other Idaho placers closed; thorium, uranium, and niobium-tantalum minerals were recovered (Hubbard, 1955, p. 55). Specific statements about reserves at the Bear Valley placer have not been released, but the combined reserves of it and deposits in the Victor and McCalla area, Montana, were reported to be 244,140 short tons of monazite, 1,660 short tons of uranothorite, 7,500 short tons of euxenite, 1,876,230 short tons of ilmenite, and 51,280 short tons of zircon in 485 million cubic yards of alluvium (Eilertsen and Lamb, 1956, p. 10).

Bear Valley Creek is a northward- and northeastward-flowing main headwater tributary to the Middle Fork of the Salmon River in Valley County. Placer deposits along the stream include three contiguous areas known, from south to north, as Upper Bear Valley or the Big Meadows area, which occupies about 3 miles in the southern part of the valley; the Central Bear Valley area, which extends for 11 miles downstream from Big Meadows; and the Lower Bear Valley area, which includes the widest downstream part of the valley (Kline and others, 1953, p. 6). Bear Valley Creek is in the south-central part of the Idaho batholith. The valley was extensively glaciated during at least two episodes of glaciation, and the present valley fill has resulted from glacial derangement of drainage in late Pleistocene time (Mackin and Schmidt, 1956, p. 376–378; 1957, p. 4). Glacial boulders as much as several feet in diameter occur along the sides of the Upper and Central Bear Valley Creek, and terminal and lateral moraines as much as several hundred feet high are present. Most of the alluvial deposits consists of fine to coarse sand and small pebbles.

The Bear Valley Creek placer was explored between 1950 and 1952 by the U.S. Bureau of Mines with 42 holes in the Upper Bear Valley or Big Meadows area, 25 holes in the Central Bear Valley area, and 16 holes in the Lower Bear Valley area (Kline and others, 1953, p. 5, 14–19). Several kinds of radioactive minerals were found. The most common are monazite and euxenite, but samarskite, fergusonite, xenotime, allanite, sphene, and zircon are also present.

The composition of concentrates from composited samples from two drill holes in the Big Meadows area was reported to be as follows:

	Percent	
	B-17	*B-36*
Ilmenite	40. 2	58. 6
Magnetite	34. 7	10. 3
Garnet	16. 2	20. 0
Quartz	2. 6	1. 0
Sphene	. 5	1. 0
Epidote	Trace	. 5
Pyroxene, amphibole, biotite	. 6	. 4
Pyrite	Trace	-------
Rutile	. 1	. 46
Zircon	Trace	. 07
Monazite	3. 5	3. 6
Radioactive opaque minerals	. 01–. 05	. 14–. 3

Two samples of monazite from the Bear Valley Creek placer were found to have the following average percentages of thorium oxide and uranium oxide:

[Analyst: U.S. Bureau of Mines (in Kline and others, 1953, p. 20)]

	Percent	
	ThO_2	U_3O_8
1	4. 37	0. 28
2	4. 82	. 27
Average	4. 60	0. 27

This abundance of thorium oxide is 0.9 percent less than that ascribed by Kremers (1958, p. 2) to commercial concentrates from the placer.

The range in tenor of the sediments in the three parts of the Bear Valley Creek placer are shown in table 47. Tenors decrease downstream. The upper part of Bear Valley Creek, the area known as Big Meadows, has the highest tenors in the radioactive heavy minerals.

The relation of the tenor of the sediments to geologic processes has been discussed by Mackin and Schmidt (1956, p. 378–379; 1957, p. 4). They showed that alluvium deposited by small streams entering Big Meadows from nonglaciated areas in an early Wisconsin glacial stage and outwash and morainal deposits formed there by early Wisconsin glaciers average 30 and 20 pounds of heavy minerals per cubic yard, respectively, whereas morainal and outwash deposits from late Wisconsin glaciers in Big Meadows average 10 pounds of heavy minerals per cubic yard. This difference was attributed to the release of heavy minerals from the crystalline rock by deep weathering during pre-Wisconsin time, making them available for transport and concentration in early Wisconsin time. The early Wisconsin glaciers scoured away the weathered mantle. Residual concentrations of heavy minerals in a weathered mantle were not available for late Wisconsin glaciers; hence, the tenor of their deposits is low. Selective transportation and dilution were also shown by Mackin and Schmidt to be involved in the downstream decrease in tenor in Bear Valley Creek. In an aggrading stream like Bear Valley Creek the heavy minerals lag behind and are buried under light minerals because the streambed is not subject to continuous reworking. Dilution of a particular placer mineral in the concentrate is caused by the discharge of low-

TABLE 47.—*Range in tenor, in pounds per cubic yard, of the main black sand minerals in the Bear Valley Creek placer, Valley County, Idaho*

Analyses from Kline, Carlson, Storch, and Robertson (1953, p. 5, 14-19). Monazite, euxenite, and columbite calculated from petrographic analyses. Magnetite, ilmenite, garnet, and zircon calculated from field estimates. Symbol used: n.d., no data]

	Bear Valley								
	Upper			Central			Lower		
	Minimum	Maximum	Average (42 samples)	Minimum	Maximum	Average (25 samples)	Minimum	Maximum	Average (15 samples)
Monazite [1]	0. 12	1. 98	0. 62	0. 02	1. 36	0. 31	0	0. 18	0. 07
Euxenite [1]	0	. 98	. 19	0	. 32	. 09	0	. 05	n.d.
Columbite [1]	0	. 75	. 12	0	. 16	. 06	0	. 06	n.d.
Magnetite [2]	. 18	17. 06	3. 45	. 20	10. 13	3. 52	n.d.	n.d.	n.d.
Ilmenite [2]	2. 40	29. 52	12. 76	2. 73	12. 92	6. 39	n.d.	n.d.	n.d.
Garnet [2]	1. 02	14. 66	7. 48	. 17	4. 61	1. 41	n.d.	n.d.	n.d.
Zircon [2]	0	. 50	. 05	0	. 17	. 03	n.d.	n.d.	n.d.

[1] Calculated from petrographic analyses.
[2] Calculated from field estimates.

tenor sediments from downstream tributaries which drain unfavorable bedrock sources. Output of monazite from the Bear Valley Creek placer is not known.

ADAMS, PAYETTE, AND GEM COUNTIES

Adams County has been cited several times for occurrences of detrital monazite after Day (1905b, p. 19) reported that 123 pounds of monazite was found in a short ton of auriferous concentrate from Meadows. This and another monazite-bearing concentrate from Meadows were subsequently listed by Day and Richards (1906b, p. 1200–1201) and are described in table 43. Monazite has also been reported from the Snake River (Schrader and others, 1917, p. 119; DeMent and Dake, 1948, p. 15; Dake, 1955, p. 56) and from a locality northwest of Meadows near the county line west of Granite Lake, Valley County (Hubbard, 1955, fig.). Further data on these localities are lacking.

Payette County was said to have placer monazite (Day, 1905a, p. 9), but there is some confusion about the location of the occurrence. Probably this reference and the report by Day and Richards (1906b, p. 1196–1197) refer to an occurrence along the Payette River in Payette County (Schrader and others, 1917, p. 119). The composition of one concentrate from this doubtful locality is shown in table 43.

Johnson Creek in Gem County was mentioned by Eilertsen and Lamb (1956, p. 12) as a monazite placer area explored by the U.S. Bureau of Mines in the early 1950's.

BOISE COUNTY

The Boise basin in Boise County is the discovery locality of monazite in Idaho. About 1896 Waldemar Lindgren of the U.S. Geological Survey identified monazite among the minerals in concentrates from gold placers along Moore Creek, Granite Creek, and Wolf Creek near Placerville, and in lake beds near Idaho City (Lindgren, 1897, p. 63; 1898, p. 677; Turner, H. W., 1902, p. 343). He observed that the grains of quartz and heavy minerals in the placers were angular and sharp edged, a characteristic that he interpreted to result from the rapid removal and accumulation of the sand from deeply disintegrated surfaces of adjacent granite masses. After Lindgren's discovery of detrital monazite in the Boise basin placers, work by the U.S. Geological Survey in 1905 (Day and Richards, 1906b, p. 1196–1197) on the mineralogical composition of monazite-bearing samples from Placerville, Centerville, Grimes Creek, and Idaho City showed that sediment and concentrates from the gold placers in the Boise basin contained from a trace to 358 pounds of monazite per short ton (table 43) and that the area had commercial concentrations of monazite (Pratt, 1906, p. 1313).

The Boise basin occupies a small marginal part of the Idaho batholith. The rocks exposed in the basin are principally granite, quartz monzonite, granodiorite, and diorite, which are intruded by porphyry, lamprophyre, and pegmatite and which are overlain by lake beds and lava flows (Ballard, 1924, p. 18–20; Kline and others, 1950, p. 7–15). Metasedimentary rocks into which the batholith was intruded are not exposed in the basin; thus, an unknown thickness of metamorphic and igneous rocks were eroded to expose the granite. Lake beds formed of partly consolidated clay and fine sand of probable Miocene age occupy the low parts of the basin, and they are covered by flows of basaltic and rhyolitic lava. The lake beds exceed 600 feet in thickness and seem to have no workable concentrations of gold or monazite, although monazite is present in them. In Quaternary time several successions of gravel were deposited on the lava and lake beds. These sediments, which have a complex geologic history and physiographic expression, are the commercial source of the gold and monazite.

The earliest attempts to mine placer monazite in Idaho were said to have been made on Grimes Creek and Granite Creek near Centerville in the Boise basin. There is some confusion among the various accounts of the enterprise, but apparently about 1903 the Centerville Mining and Milling Co., owning placer ground on these streams, began to experiment with ways to recover a monazite separate from the concentrates produced at the gold placers. In 1906 the company constructed a plant and separated 2 or 3 short tons of monazite but did not ship the product. The plant was enlarged in 1907 and 1909, and small quantities of monazite were produced but were not marketed. During 1910 the plant was destroyed by forest fire and was not rebuilt. When the plant was destroyed the records were lost, and no authentic production figures have survived (Metall. and Chem. Eng., 1910; Salt Lake Mining Rev., 1910; Mining Sci., 1910; Sterrett, 1911, p. 901; Jones, E. L., 1916, p. 97; Pratt, 1916, p. 62; Shannon, 1926, p. 411; Staley and Browning, 1949, p. 2; Kline and others, 1950, p. 24; Kauffman and Baber, 1956, p. 3). Against this probable record is the seemingly erroneous report by Santmyers (1930, p. 14) that this enterprise was a factor in the monazite industry of the United States from 1903 through 1910.

A renewal of commercial interest in the monazite of Idaho, and particularly of the Boise basin, took place in 1922 (Campbell, Stewart, 1922, p. 28) and 1938 (Mining Jour. [Phoenix], 1938), but no monazite was produced and, during the mid-1920's, the Centerville placers were regarded as an uneconomic source for thorium minerals (Ballard, 1924, p. 33). In 1941 and 1948 the possible commercial importance of the placer monazite in Boise County was again being pointed out (Campbell, Arthur, 1941, p. 5; Mining Cong. Jour., 1948, p. 70). Commercial recovery of monazite in the Boise basin was undertaken in a small way in 1946 and continued as a minor byproduct venture of gold mining until 1948 at the Baumhoff-Marshall dredge near Centerville and the Idaho-Canadian dredge near Idaho City. During this time a part of the jig concentrate from these dredges was pumped ashore and stockpiled. Some of the concentrate was trucked to McCall for the separation of monazite. Through 1948 this operation produced 40 short tons of monazite (Kline and others, 1950, p. 24). In October 1948 the U.S. Bureau of Mines did some preliminary surface sampling for monazite in the Boise basin. Between August and November 1949 the Bureau, under the auspices of the U.S. Atomic Energy Commission, drilled the placers. This program showed that the greatest reserves of monazite were in the enormous volume of tailings from early gold mining on Moore Creek, Granite Creek, Grimes Creek, and Elk Creek. Considerable reserves of monazite were also found in unmined placers on tributaries to Granite Creek, mainly Wolf Creek, Fall Creek, and Canyon Creek, and also on Moore Creek (Kline and others, 1950, p. 5, 35).

Black sand from the different gold placer areas in the Boise basin was found by the U.S. Bureau of Mines to range in weight from 2.71 to 8.84 pounds per cubic yard of gravel and to contain from 7 to 13 percent of monazite (table 48).

The monazite separate produced at the old Centerville plant in the early 1900's was described in company statements as consisting of 95 percent of monazite and containing 5–5.2 percent of ThO_2 (Salt Lake Mining Rev., 1910; Sterrett, 1911, p. 902); however, two analyses of monazite concentrates of unknown purity from the Centerville area, made by W. F. Hillebrand in 1906, disclosed 4.42 and 4.60 percent of ThO_2 and the mean of five analyses made by R. C. Wells in 1911 showed 3.01 percent of ThO_2 (Sterrett, 1911, p. 902–903). Analyses of four samples of relatively pure monazite from the Boise basin showed the following percentages of thorium and uranium oxides:

[Analyst: U.S. Bureau of Mines in 1949 (in Kline and others, 1950, p. 32)]

	Percent	
	ThO_2	U_3O_8
1	2.98	0.100
2	3.06	.105
3	2.9	No data
4	4.0	No data
Average	3.2	0.1

Impure monazite concentrates from dredges near Idaho City and Centerville, Boise basin, were reported by Staley (1952, p. 308), and a sample of pure monazite from the Boise basin was reported by Staley and Browning (1949, p. 5).

Chemical analyses, in percent, of monazite from Boise basin

	Vicinity of Idaho City	Near Centerville	Boise basin
RE_2O_3	34.2	62.3	66.8
ThO_2	1.6	1.9	2.2
P_2O_5	14.3	22.7	26.7
ZrO_2	19.0	3.8	.7
SiO_2			.6
TiO_2			.6
Ca, Al, and Fe oxides			1.6

Five samples of pure monazite from placers in the Boise basin near Idaho City and Placerville were reported by Jaffe, Gottfried, Waring, and Worthing (1959, p. 95) to have alpha activity between 2,634 and 3,241 alpha particles per milligram per hour, indicating only moderate abundances of thorium oxide in the monazite.

Some exploration was conducted by the U.S. Bureau of Mines on the Rabbit Creek placer near Idaho City, Boise County, but a description of the monazite occurrence has not been published (Eilertsen and Lamb, 1956, p. 12). Monazite from Rabbit Creek was analyzed by the Bureau and was found to contain 5.50 percent of ThO_2 and 0.36 percent U_3O_8 (Kauffman and Baber, 1956, p. 6). Elsewhere in the area the Lakow Flats placer was said to have monazite but is not a commercial source (Armstrong, 1953, p. 217); the Summit Flats placer was examined for monazite by

TABLE 48.—*Principal heavy minerals in percent, of concentrates from gold placers in the Boise basin, Boise County, Idaho*

[Modified from Kline, Carlson, and Griffith (1950, p. 17). Based on field estimate]

	Granite Creek	Wolf Creek	Grimes Creek	Elk Creek-Moore Creek	Grass Flats	Flat Creek
Concentrate, lb per cu yd	8.13	7.45	4.78	2.71	4.32	8.84
Monazite	12	11	13	7	8	7
Ilmenite	37	42	38	17	40	27
Magnetite	27	16	26	3	39	54
Garnet	9	8	10	54	3	4
Zircon	15	23	13	19	10	8

the U.S. Bureau of Mines, but an evaluation of the deposit has not been published (Kauffman and Baber, 1956, p. 7). Porter Creek west of Quartzburg was said to be monazite bearing (Hubbard, 1955, fig.).

A few miles north of the northwestern part of the Boise basin, monazite was reported (Day and Richards, 1906b, p. 1196–1197) from the North Fork of the Payette River at Garden Valley (table 43), Boise County. In the same area monazite was also reported from the North Fork of the Payette River at Banks (Hubbard, 1955, fig.).

ADA, OWYHEE, ELMORE, AND CUSTER COUNTIES

Ada County was mentioned in the early 1900's as a source for detrital monazite (Day, 1905b, p. 21; Day and Richards, 1906a, p. 152; 1906b, p. 1194–1195). Two concentrates from around Boise contained more than 200 pounds of monazite per short ton (table 43), but apparently none of the occurrences is an exploitable deposit. Dry Creek, north of Boise, was explored for monazite in the early 1950's by the U.S. Bureau of Mines.

Oreana in Owyhee County was the source of a monazite-bearing concentrate (table 43) described by Day and Richards (1906b, p. 1200–1201) and subsequently cited frequently (Sanford and Stone, 1914, p. 67; Hill, J. M., 1915, p. 282–283; Schrader, Stone, and Sanford, 1917, p. 119; DeMent and Dake, 1948, p. 15; Dake, 1955, p. 56). Monazite was also reported in the alluvium along Jordan Creek near DeLamar and along a tributary to Rabbit Creek south of Murphy, Owyhee County (Hubbard, 1955, fig.).

The Dismal Swamp placer is at the headwaters of Buck Creek about 8 miles northwest of Rocky Bar, Elmore County. Sampling of the deposit in 1952 and 1953 by private interests, the U.S. Geological Survey, and the U.S. Bureau of Mines showed that it contained niobium-, tantalum-, and uranium-bearing minerals and a small amount of monazite but that the deposit was probably not large enough to be exploited (Armstrong, 1953, p. 217; 1957a, p. 386; Shelton and Stickney, 1955, p. 3). According to Armstrong (1957a, p. 385–388), the placer is in a narrow valley near the south end of the Idaho batholith at a point about midway between the east and west margins of the batholith. Glaciation during late Wisconsin time did not affect the Dismal Swamp area; hence, the granodiorite underlying the deposit is weathered to gruss for a depth of at least 2 feet. Alluvium consists of products derived by local stream erosion and slope wash from the weathered surface of the granodiorite. A concentrate from the deposit was reported to have the following composition (Shelton and Stickney, 1955, p. 3):

	Weight percent
Columbite	67.47
Samarskite	6.14
Zircon	5.58
Ilmenite	5.12
Garnet	3.70
Monazite	3.49
Quartz and feldspar	8.50
Total	100.00

Other minerals noted in concentrates from the Dismal Swamp placer are anatase, cassiterite, cyrtolite, magnetite, rutile, titaniferous magnetite, topaz, and xenotime (Armstrong, 1957a, p. 386). Allanite was said to be a common accessory mineral in the rocks of this region (Anderson, 1943, p. 5, 8; Smith and others, 1957, p. 372), but it was unreported in the concentrates, possibly owing to weathering. The minerals seem to be original constituents of the granodiorite and small pegmatite dikes that cut the granodiorite.

The monazite was said by Shelton and Stickney (1955, p. 3) to contain 50.8 percent total RE_2O_3 plus ThO_2, 1.4 percent Nb_2O_5, and less than 1 percent Ta_2O_5. Either there is some error in this analysis or the material analyzed was not pure monazite, because the abundance assigned to the RE_2O_3 plus ThO_2 is 10–15 percent too low.

The tenor of the gravel in the placer was reported to be 1.40–1.87 pounds per cubic yard of weakly magnetic minerals containing 14–20 percent $Nb_2O_5 + Ta_2O_5$, but the actual amount of monazite was not stated (Armstrong, 1957a, p. 390–392). It seems to be small.

Alexander Flats on the Middle Fork of the Boise River, Elmore County, was the source of detrital monazite analyzed by the U.S. Bureau of Mines and found to contain 5.98 percent ThO_2 and 0.18 percent U_3O_8 (Kauffman and Baber, 1956, p. 6).

Placer monazite has been found near the extreme south end of the exposed part of the Idaho batholith at Mud Flats in Elmore County. Monazite from the placer was found by the U.S. Bureau of Mines to contain an unusually large amount of thorium oxide for monazite from the Idaho batholith: 6.24 percent of ThO_2 and 0.22 percent U_3O_8 (Kauffman and Baber, 1956, p. 6).

Custer County was said to have occurrences of detrital monazite at Valley Creek, Meadow Creek, Stanley Creek, Kelly Creek, Yankee Fork Gold Creek, Williams Creek, and Pigtail Creek (Eilertsen and Lamb, 1956, p. 11–12; Savage, 1960, fig. 1). None of these monazite deposits has been described in detail, but it was stated that the notable gold placers along Stanley Creek and Yankee Fork gave only slight indications of monazite (Staley, 1952, p. 305). Except for Yankee Fork and Pigtail Creek, these monazite occurrences were examined by the U.S. Bureau of Mines in the early 1950's (Eilertsen and Lamb, 1956, p. 11–12), and monazite from Valley Creek was determined to have 3.31 percent ThO_2 and 0.18 percent U_3O_8 (Kauffman and Baber, 1956, p. 6). Allanite was said to be a common accessory mineral in the granitic rocks in the Stanley Creek area (Smith and others, 1957, p. 372), but its concentration in the placers is doubtful.

LEMHI, CAMAS, AND BLAINE COUNTIES

Concentrates from Arnett Creek, Wards Gulch, and unnamed streams, probably including Moose Creek (Hubbard, 1955, fig.), in the Leesburg Basin gold placer district, Lemhi County, were shown by Day (1905b, p. 20) to contain from 0.5 to 10 pounds of monazite per short ton. Day and Richards (1906b, p. 1198–1199) observed as much as 44 pounds of monazite per short ton of concentrate from the Leesburg Basin (table 43). Monazite was said to be sufficiently concentrated in a placer near the junction of Smith Gulch and Napias Creek in the Leesburg area that it could be recovered in a gold-dredging operation (Shockey, 1957, p. 36). The general tenor of the auriferous sediments in the Leesburg district, however, was too low for the economic recovery of monazite (Staley, 1952, p. 305).

Gold placers on tributaries to the Lemhi River between Salmon and Tendoy and at Gibbonsville on the North Fork of the Salmon River in Lemhi County have been described as having very sparse monazite (Staley, 1952, p. 305; Savage, 1960, fig. 1). Minor amounts of monazite have been found in the alluvium of streams tributary to the Salmon River between the towns of Shoup and North Fork in northern Lemhi County where low-thorium oxide monazite forms segregations in marble (Abbott, 1954, p. 5).

The Camp Creek placer area is an irregularly shaped tract about 0.5 mile wide and 3.25 miles long that extends southeasterly down Camp Creek where that stream is crossed by the line between Camas County and Blaine County (Robertson and Storch, 1955a, p. 7). The northern part of the placer is in Camas County and the southern part is in Blaine County. Granodiorite and quartz monzonite of the Idaho batholith are exposed near the placer, but in the northeastern part of the Camp Creek basin these rocks are covered with basaltic flows. During 1954 the deposit was drilled by the U.S. Bureau of Mines and found to contain appreciable magnetite, ilmenite, sphene, hornblende, uranothorite, and several sparse minerals among which was monazite (table 49).

TABLE 49.—*Mineralogical composition, in percent, of concentrates from the Camp Creek placer, Camas and Blaine Counties, Idaho*

[Analyst: U.S. Bur. of Mines (in Robertson and Storch, 1955, p. 12). Symbol used: --, absent]

	Drill hole CC-1	Test pit	
		TC-1	TC-2
Epidote	1–2	1–2	2.5–3.5
Pyroxene, hornblende, and other minerals	1–2	2	3–4
Garnet	<0.2	<0.2	<0.2
Ilmenite	9–11	26–30	26–38
Magnetite	68–72	29–33	15–17
Monazite	.01	.1	.1
Pyrite	Trace	Trace	Trace
Quartz	9–11	16–20	13–15
Zircon	<1	.5–.8	2–3
Sphene	4–5	10–12	16–18
Uranothorite	.3	1.2	2.0
Colored opaque minerals	.5	4–5	3–4
Black opaque minerals	.5	<1	<1
Rutile	Trace	--	Trace
Gold	Trace	--	--

Although the volume of the deposit is large, the placer is not a significant source for monazite.

Monazite was found by the U.S. Bureau of Mines in 1954 to be present in trace amounts in the alluvium of Rock Creek, Blaine County (Robertson and Storch, 1955b, p. 11–12). The drainage basin of the stream is underlain by granite and lava flows, and the heavy minerals in the Rock Creek placer resemble those in Camp Creek: dominant magnetite, sphene, hematite, hornblende, biotite, epidote, pyroxene, and allanite, and minor ilmenite, zircon, garnet, cyrtolite, columbite, thorite or uranothorite, and a trace of monazite.

LINCOLN, MINIDOKA, BANNOCK, AND BINGHAM COUNTIES

Black sand from Shoshone, Lincoln County, was reported by Day (1905b, p. 22) and Day and Richards (1906a, p. 153; 1906b, p. 1198–1199) to contain 26 pounds of monazite per short ton of concentrate (table 43), but the source of the concentrate was not specifically identified. It may have been from the Wood River, which leads to the Camp Creek and Rock Creek placers, where a little monazite has been found.

A concentrate from the Snake River near Minidoka, Minidoka County, was reported by Day and Richards (1906b, p. 1198–1199) and J. M. Hill (1915, p. 282–283) to contain 8 pounds of monazite per short ton (table 43).

Detrital monazite apparently occurs in Bannock County, but the locality was not given (Day, 1905a, p. 9).

Sand from the Snake River in Bingham County was said by Day and Richards (1906b, p. 1194–1195) and J. M. Hill (1915, p. 282–283) to have a trace of monazite (table 43).

ILLINOIS

HICKS DOME PRIMARY MONAZITE

A remarkable occurrence of yttrium-rich monazite at Hicks Dome, Hardin County, was described by Trace (1960). He noted that Hicks Dome is a tectonic feature which has been previously described as an incipient cryptovolcanic structure. The dome covers about 100 square miles in western Hardin County and affects sedimentary rocks of Devonian, Mississippian, and Pennsylvanian age. At the center of the dome in an area comprising about 2 square miles, limestone, chert, and black shale of Devonian age attain dips as great as 15° and are accompanied by a few tabular to pipelike masses of breccia and an altered mafic dike. The breccia zones in this central area are anomalously radioactive. They also contain more beryllium, rare earths, niobium, and zirconium than the unbrecciated rocks.

The radioactive mineral in the breccia zones at the center of Hicks Dome was identified by Trace (1960, p. B63) as monazite. The monazite occurs with florencite, a cerium-aluminum phosphate, and fluorite in very fine-grained carbonate matrix between fragments of limestone, chert, and black shale in the breccia, but it has not been found in the sedimentary rocks. Contacts between the fragments of sedimentary rock in the breccia and the matrix are sharp, and the fragments of sedimentary rocks are apparently unaltered.

The monazite forms small, soft, earthy rounded to subrounded brownish-yellow grains about 0.004–0.01 inch in diameter. Preliminary study by X-ray diffraction demonstrated that the mineral has the monazite cell structure but that the size of the cell is small. A quantitative spectrochemical analysis showed that the monazite is unusually rich in the yttrium earths and lean in the cerium earths and that it has the following composition:

[Analyst: H. J. Rose, Jr. (in Trace, 1960, p. B64)]

	Percent		Percent
Ce_2O_3	16	P_2O_5	29
La_2O_3	11	SiO_2	4.4
Nd_2O_3	6	Al_2O_3	2.2
Sm_2O_3	2	Fe_2O_3	6.6
Gd_2O_3	1.5	TiO_2	2.7
Pr_2O_3	2.5	CaO	3.8
Dy_2O_3	1.5	MgO	.2
Y_2O_3	4.2		
ThO_2	4.4	Total	98

The unusually great amount of yttrium was regarded by Trace as possibly accounting for the small cell size of the monazite. Trace also noted that the relatively low content of cerium and lanthanum and great amount of yttrium in the monazite resembles the composition of relatively unfractionated, or primitive, monazite as described by Murata, Rose, and Carron (1953, p. 296–297) and by Murata, Rose, Carron, and Glass (1957, p. 148–150). The percentage of thorium oxide in this monazite, 4.4 percent, is remarkably high for monazite in carbonate rocks.

The observations that the monazite occurs in a cryptovolcanic structural feature, that it is relatively unfractionated, and that it has an unusually large amount of thorium oxide for monazite in a calcareous environment are here interpreted to mean that the monazite formed with little fractionation at depth and was transported with explosive rapidity toward the surface. Rapid upward transport prevented reactions that would have lead to lower abundances of thorium and yttrium in the monazite or possible total elimination of a monazite phase. The monazite from Hicks Dome is the only known occurrence of monazite in a cryptovolcanic structural feature.

DETRITAL SOURCES

Very minor amounts of detrital monazite are present among the accessory heavy minerals in sand of Cretaceous age exposed in southern Illinois southwest of Hicks Dome. Monazite was reported in three samples of sand from the vicinity of Boaz, Massac County; single samples near Karnak and Olmsted, Pulaski County; and two samples near Sandusky, Alexander County. The composition of the monazite-bearing suites of heavy minerals from the sand is shown in table 50. Resistate minerals from metamorphic rocks such as kyanite, staurolite, and sillimanite together with resistate minerals of igneous or metamorphic origin like rutile, tourmaline, zircon, and ilmenite accompany the monazite in the Cretaceous sedimentary rocks. Xenotime is also present in very small amounts.

Only 1 out of the 18 samples from glacial outwash examined by Lamar and Grim contained minor accessory monazite (table 50). It came from the West Chicago area in McHenry County. Unstable minerals of dominantly igneous and metamorphic origin like augite, diopside, hypersthene, hornblende, and garnet accompany the monazite, and the stable, dominantly metamorphic minerals common in the Cretaceous sand of southern Illinois, are missing from the outwash.

Two river sands of the nine samples of Recent lake and river sand were found to have minor amounts of

TABLE 50.—*Mineralogical composition of monazite-bearing suites of heavy minerals from alluvium of Recent age, glacial outwash gravel of Wisconsin age, and sand of Cretaceous age in Illinois*

[Modified from Lamar and Grim (1937, p. 80–81). Symbols used: A, abundant; C, common; R, rare; VR, very rare; Ab, absent]

	1	2	3	4	5	6	7	8	9	10
Augite	C	R	A	Ab	Ab	Ab	Ab	Ab	Ab	Ab
Diopside	C	R	C	Ab	Ab	Ab	Ab	Ab	Ab	Ab
Epidote	C	R	C	VR	VR	VR	Ab	VR	Ab	Ab
Garnet	C	A	A	Ab	Ab	Ab	Ab	Ab	Ab	Ab
Hornblende	A	VR	A	Ab	Ab	Ab	Ab	Ab	Ab	Ab
Hypersthene	R	C	C	Ab	Ab	Ab	Ab	Ab	Ab	Ab
Ilmenite	Ab	R	Ab	C	C	R	C	VR	C	C
Kyanite	VR	A	Ab	A	A	A	A	C	A	A
Leucoxene	Ab	R	Ab	C	R	R	C	VR	C	C
Magnetite	C	R	A	Ab	VR	VR	R	R	R	VR
Monazite	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR
Muscovite	C	C	Ab	C	A	A	A	A	C	A
Rutile	VR	C	Ab	C	C	C	C	C	C	C
Sillimanite	VR	R	Ab	C	R	R	Ab	VR	R	R
Staurolite	VR	C	Ab	A	C	A	C	C	C	C
Tourmaline	C	C	Ab	C	C	C	A	C	A	A
Xenotime	VR	VR	Ab	VR	VR	Ab	VR	VR	VR	Ab
Zircon	C	C	Ab	A	A	A	A	A	A	A

Recent river sand:
1. Mississippi River sand near Gladstone, Henderson County. Contains abundant chlorite, rare biotite and enstatite, and very rare wollastonite.
2. Ohio River near Olmsted, Pulaski County. Contains common chlorite.

Glacial outwash gravel of Wisconsin age:
3. West Chicago, McHenry County.

Sand of Cretaceous age:
4–6. Near Boaz, Massac County. Sample 6 contains very rare andalusite.
7–8. Near Sandusky, Alexander County.
9. Near Olmsted, Pulaski County.
10. Near Karnak, Pulaski County.

monazite (table 50). One was from the Mississippi River near Gladstone in Henderson County, and the other was from the Ohio River near Olmsted, Pulaski County, where the shore of the river is faced by bluffs of Cretaceous sand which contains a small amount of monazite. The river sands contain stable and unstable minerals including species present in both the Cretaceous and Wisconsin sediments.

Two concentrates from the bed of the Mississippi River at Cairo, Alexander County, just downstream from the monazite-bearing Cretaceous sediments, were examined by Russell (1937, p. 1319) and found to contain less than 1 percent of monazite.

INDIANA

Black sand of unspecified origin from the vicinity of Michigan City, La Porte County, was found by Day and Richards (1906b, p. 1200–1201) to contain 34 pounds of monazite and a small amount of gold per short ton of concentrate:

	Pounds per short ton
Magnetite	1, 181
Chromite	2
Garnet	370
Monazite	34
Zircon	66
Quartz	344
Total	1, 997

Possibly the material was sand from the shore of Lake Michigan.

IOWA

Heavy-mineral suites from samples of loess and till of Pleistocene age from several localities in Iowa were examined by P. T. Miller and the results compiled by Kay and Graham (1943, p. 182). All samples of Peorian Loess and Iowan till were found to be monazite bearing (table 51). The till contained three times as much monazite as the loess, but even in the richest samples the monazite only amounted to 0.52 percent of the total heavy minerals. Five samples of monazite-bearing sediments were taken from two localities, North Liberty in Johnson County and West Union in Fayette County.

A trace of monazite was observed by J. W. Whitlow (oral commun., 1956), U.S. Geological Survey, in the fine sand discarded at a sand and gravel-washing plant just north of Bellevue, Jackson County. Gravel is derived from glacial till. Garnet is abundant and magnetite, zircon, and gold in small amounts are also present.

KENTUCKY AND MISSOURI

Recent bottom sediments of the Mississippi River at Hickman, Fulton County, Ky., contain sparse monazite. Concentrates from five samples of sediment from the Kentucky and Missouri sides of the river had monazite, but in each sample the monazite made up less than 1 percent of the concentrate (Russell, 1937, p. 1318).

LOUISIANA

Monazite is a scarce component of concentrates made from sand of Pleistocene and Recent age in Louisiana. Two out of five samples of sand of Pleistocene age were found by E. P. Thomas (Woodward and Gueno, 1941, p. 9–10) to contain about 2 percent of heavy minerals among which monazite was a minor accessory (table 52). One concentrate was from an exposure of the Williana Formation near Fullerton in Vernon Parish, and the other was from the Prairie Formation at Merryville in Beauregard Parish.

Monazite rarely constitutes as much as 2 percent of the heavy minerals separated from sediments in the present bed of the Mississippi River in Louisiana (Russell, 1937, p. 1330). At Angola, West Feliciana Parish, all four of the concentrates contained monazite. In three concentrates monazite was less than 1 percent of the concentrate, and in one it was 1 percent. At Baton Rouge, East Baton Rouge Parish, monazite was present as less than 1 percent of the concentrate in two concentrates and as 1 percent in one concentrate. All 21 concentrates from sediment in the present channel of the Mississippi River at New Orleans, Orleans Parish, contained monazite. In 16 concen-

TABLE 51—*Mineralogical composition, in percent, of monazite-bearing suites of heavy minerals from Pleistocene loess and till in Iowa*

[Modified from analyses by P. T. Miller (in Kay and Graham, 1943, p. 182). Symbol used: --, absent]

	Peorian Loess				Iowan till			Kansan till
	Except North Liberty and West Union cuts	North Liberty cut	West Union cut	All Iowa	Except West Union cut	West Union cut	All Iowa	
Pyrite	7. 92	1. 33	2. 01	4. 05	6. 60	1. 65	3. 30	2. 55
Magnetite and ilmenite	19. 20	13. 78	19. 15	17. 69	10. 58	20. 20	16. 99	11. 12
Hornblende	27. 32	36. 29	29. 37	30. 76	43. 30	32. 03	35. 69	38. 14
Pargasite	. 62	1. 24	1. 98	1. 02	1. 10	1. 76	1. 51	1. 09
Glaucophane	. 32	1. 48	1. 81	1. 06	. 55	1. 85	1. 48	. 42
Actinolite	. 50	1. 73	. 73	1. 29	1. 07	. 61	. 76	. 78
Tremolite	. 11	. 75	. 55	. 52	--	--	--	1. 09
Hypersthene	1. 13	1. 46	2. 73	1. 34	2. 75	1. 66	2. 02	1. 81
Enstatite	. 57	1. 52	. 63	1. 18	1. 08	. 24	. 52	1. 33
Augite	2. 29	12. 02	25. 09	6. 95	5. 30	1. 92	3. 05	3. 45
Aegerite-augite	. 11	. 02	. 23	. 09	--	. 36	. 24	. 54
Aegerite	. 27	. 35	. 36	. 32	. 07	. 16	. 13	. 54
Chlorite	3. 56	1. 21	. 12	2. 05	. 80	. 18	. 39	1. 57
Andalusite	. 34	1. 35	. 92	. 99	. 34	. 95	. 75	--
Epidote	6. 35	10. 35	5. 02	8. 08	10. 55	3. 30	5. 72	7. 51
Zircon	4. 35	3. 13	7. 26	4. 38	3. 27	9. 26	7. 26	5. 55
Garnet	5. 80	5. 51	8. 07	6. 30	7. 48	10. 18	9. 26	15. 22
Tourmaline	. 49	1. 81	2. 89	1. 51	. 88	1. 72	1. 44	. 49
Sphene	. 99	. 82	1. 90	. 89	. 29	1. 71	1. 24	. 78
Biotite	15. 71	. 76	2. 36	6. 66	. 63	2. 14	1. 64	3. 77
Staurolite	. 30	. 95	. 54	. 70	. 69	1. 09	. 96	--
Topaz	. 44	. 21	2. 96	. 29	. 19	1. 77	1. 24	. 18
Kyanite	. 30	. 34	--	. 33	. 75	--	. 08	. 73
Rutile	--	. 38	1. 35	. 25	. 71	. 37	. 48	. 73
Brookite	--	--	. 12	--	. 10	. 13	. 12	--
Barite	. 11	. 99	--	. 68	. 13	--	. 05	. 01
Monazite	. 16	. 08	. 32	. 11	. 27	. 39	. 35	. 12
Riebeckite	. 08	. 07	. 10	. 07	. 15	. 52	. 40	--
Basaltic hornblende	. 46	. 07	. 60	. 21	. 28	1. 71	1. 23	. 54
Spinel	--	--	. 68	--	--	. 36	. 24	--
Anthophyllite	. 08	--	. 28	. 03	. 02	. 54	. 37	. 95
Hedenbergite	--	--	. 17	--	--	. 24	--	--
Other minerals	. 18	. 08	--	. 12	. 92	1. 21	1. 11	--

TABLE 52.—*Mineralogical composition of concentrates from two monazite-bearing sand units of Pleistocene age in Louisiana*

[Modified from analyses by E. P. Thomas (Woodward and Gueno, 1941, p. 10). No quantitative range of abundance given in original report. Symbol used: Ab, absent]

	Prairie Formation	Williana Formation
Magnetite	MA	MA
Ilmenite	VA	VA
Zircon	A	A
Leucoxene	C	C
Tourmaline	R	C
Staurolite	R	C
Kyanite	R	C
Rutile	R	R
Sillimanite	VR	VR
Diopside	VR	Ab
Spodumene	VR	Ab
Epidote	VR	VR
Allanite	VR	Ab
Monazite	VR	R
Limonite	Ab	C
Hematite	Ab	C
Collophane	Ab	R
Hornblende (blue-green)	Ab	VR
Andalusite	Ab	VR

trates the monazite was less than 1 percent of the concentrate. The monazite reached abundances of 1 percent in three concentrates and 2 percent in two concentrates. At Profit Island, Plaquemines Parish, two concentrates contained 2 percent of monazite, three had 1 percent, and seven had less than 1 percent.

Out of 16 concentrates from sand and silt in the Mississippi Delta, 7 contain sparse monazite (table 53). Among the monazite-bearing sediments represented in the samples are Recent dune sand from Cat Island and subsurface sand and silt from Freemason Island and Chandeleur Island, St. Bernard Parish, subsurface and Recent surface sand from Southeast Pass, and subsurface and bottom samples from North Barataria Bay, Plaquemines Parish.

MAINE

The occurrence of monazite in the crystalline rocks, principally pegmatite, of Maine was mentioned at least as early as 1891 (Derby, 1891a, p. 205; Mining and Sci. Press, 1902) in surveys of the distribution of the mineral in the United States, but primary or secondary deposits of economic importance have not been found. The known primary deposits are mostly localities where monazite can only be obtained in specimen

TABLE 53.—*Mineralogical composition, in frequency percent, of monazite-bearing concentrates from sediments in the Mississippi Delta in St. Bernard and Plaquemines Parishes, La., and Cat Island, Harrison County, Miss.*

[Modified from Dohm (1936, p. 378–379). Symbols used: P, present; R, rare; VR, very rare; Tr., trace; --, absent]

	1	2	3	4	5	6	7
Magnetite [1]	0.3	6.3	1.3	Tr.	1.9	0.1	2.7
Ilmenite (traces of chromite)	26	10	4	7	20	4	29
Leucoxene	--	5	3	6	2	8	9
Limonite and hematite	--	3	2	7	9	2	13
Pyrite	--	P	1	R	--	P	2
Rock grains	--	6	P	4	1	2	3
Epidote	--	12	6	11	11	12	5
Allanite	--	VR	VR	--	--	--	--
Chlorite	--	--	5	--	--	--	--
Biotite	--	VR	19	R	R	R	P
Muscovite	--	--	13	P	--	R	2
Augite and diopside	--	14	4	15	12	15	1
Diallage	--	VR	--	R	R	--	--
Hypersthene	--	2	R	P	2	1	P
Hornblende:							
Common	--	7	3	7	4	10	1
Blue-green	--	10	3	7	6	6	3
Basaltic	--	P	P	2	1	2	R
Actinolite and tremolite	--	5	4	11	4	7	P
Apatite	--	3	P	P	1	1	R
Zircon	61	4	2	2	4	R	9
Sphene	--	2	P	3	1	3	R
Rutile	8	VR	VR	R	P	--	4
Monazite	1	R	VR	VR	P	VR	R
Staurolite	R	VR	--	R	--	--	6
Sillimanite	--	P	VR	R	R	R	R
Kyanite	2	VR	VR	P	R	R	6
Chloritoid	--	VR	--	VR	--	--	--
Tourmaline:							
Brown or yellow to greenish brown or black	--	P	VR	VR	R	P	2
Brown or yellow to olive green	--	VR	--	VR	--	--	--
Colorless to yellow or brown	--	R	--	R	--	VR	R
Garnet:							
Colorless	R	4	P	5	8	4	P
Brown	--	VR	--	--	--	R	--
Pink to apricot	--	P	--	VR	3	P	R
Dolomite and siderite	R	11	P	12	6	1	--
Collophane	--	P	R	VR	1	R	R

[1] Magnetite removed by magnet and expressed as weight percent of the concentrate. Abundances of the other minerals are expressed as frequency percent of the magnetite-free concentrate.

1. Extremely well sorted dune sand from Cat Island, Harrison County, Miss.
2. Fairly well sorted fine sand taken at 8 feet below surface in a boring on the north end of Freemason Islands just east of Neptune Point.
3. Fairly well sorted silt taken at 18 feet below surface in a boring on the windward side of Chandeleur Island group east of lower Freemason Islands.
4. Well-sorted very fine grained sand taken at 17 feet below surface in a boring in the natural levee of Southeast Pass.
5. Extremely well sorted Mississippi River sand of Recent age taken from the surface of a mudlump at the mouth of Southeast Pass.
6. Fairly well sorted very fine sand taken at 13.5 feet below surface in a boring on the south edge of a small island 1.5 miles to the southeast of St. Marys Point in North Barataria Bay.
7. Well-sorted sand from bottom 0.5 mile to the southeast of sample 6.

quantity. Whatever placer deposits may have been formed in pre-Pleistocene time were eroded by the continental glaciation, and sizable placers have not been formed since the last glaciation.

Monazite occurrences in pegmatite in the Topsham feldspar district have been most often described in the literature. The district is about 1 mile wide and 8 miles long and extends north-northeastward from Topsham to Bowdoinham, Sagadahoc County (Shainin, 1948, p. 5; Cameron and others, 1954, p. 5). High-grade metamorphic rocks of dominantly sedimentary origin underlie the area. They include coarse-grained biotite gneiss, biotite-hornblende gneiss, hornblende gneiss, and quartz-andesine-diopside gneiss. Interlayered with the metasedimentary rocks are a variety of granitic gneisses, quartz-plagioclase aplite, and granitic pegmatite. Many of the masses of aplite cut across the foliation of the metamorphic rocks, and the pegmatite cuts across all the other rocks. Late mafic dikes of probable Triassic age transect all other rocks in the Topsham area. Feldspar has been mined from or prospected for at many large openings and thousands of small pits, and in a very few of these places specimens of monazite have been found (Morrill, 1958, p. 50).

Several pegmatite quarries immediately west of Topsham at a locality known as Standpipe Hill have been the source of monazite crystals as much as 1 by 1⅜ inches in size (Yedlin, L. N., 1942, p. 206). The crystals of monazite are euhedral twinned lustrous-brown grains. They tend to occur in microcline at the contact between the microcline and biotite and are in places associated with samarskite.

Monazite from a pegmatite dike in the Topsham district had the following composition:

[Analyst: Edith Kroupa in 1936 (in Lane, 1937, p. 58; see also Rodgers, 1952, p. 421)]

	Percent		Percent
RE_2O_3	40.59	PbO	0.181
ThO_2	6.70	MnO	.72
U_3O_8	------	SO_4	.25
P_2O_5	16.21	$H_2O-(110°)$	.52
SiO_2	13.91	Loss on ignition (110°-1,000°)	3.29
Al_2O_3	.63	Insoluble residues	9.78
FeO	------		
Fe_2O_3	7.21		
CaO	.91	Total	101.31
MgO	.41		

Monazite was questionably reported by Derby (1891a, p. 205; Twinem, 1932a, p. 31; 1932b, p. 31; Morrill, 1959, p. 58) to occur as a minor accessory mineral in gneiss at Blue Hill (East Blue Hill), Hancock County.

Pegmatite near Auburn, Androscoggin County, was said to be monazite bearing (Twinem, 1932a, p. 31).

MARYLAND

Monazite was found by Dryden and Dryden (1946, p. 92–94) to be one of the minor accessory minerals in the Wissahickon Schist of northern Maryland, but specific occurrences were not listed.

The heavy minerals in 10 samples of sedimentary rocks of Eocene age from southern Maryland were examined by Lincoln Dryden (1932, p. 518–519). Monazite was found to occur as scarce grains associated with similarly sparse andalusite, corundum, topaz, brookite, dumortierite, glaucophane, anatase, zoisite, sphene, muscovite, chlorite, hypersthene(?), and clinozoisite(?). The principal minerals in concentrates from the sedimentary rocks and their average order of abundances were zircon, 35 percent; staurolite, 30 percent; garnet and rutile, 8 percent each; epidote, 7 percent; tourmaline, 6 percent; kyanite, 3 percent; chloritoid, 2 percent; and sillimanite, 1 percent. Localities of individual samples were not listed.

Recent beach sand at Ocean City, Worcester County, contains a trace of monazite (Day and Richards, 1906b, p. 1202–1203):

	Pounds per short ton
Magnetite	Trace
Ilmenite	138
Garnet	12
Olivine	Trace
Monazite	Trace
Zircon	19
Quartz	1, 816
Unclassified	15
Total	2, 000

Also reported is about a hundredth of an ounce of gold per short ton of natural beach sand.

MASSACHUSETTS

South Orange in Franklin County was mentioned as early as 1852 as a monazite locality, but the nature of the occurrence was not specified (Shepard, 1852, p. 109). In 1891 monazite was reported from gneiss at Westford and Ayer, Middlesex County, and may have been observed at Milford and Dedham, Norfolk County (Derby, 1891a, p. 205).

A zone of rocks characterized by above-background amounts of radioactivity was described by D. H. Johnson (1951, p. 6–7) as extending northeastward from the northeast border of Connecticut to north-central Massachusetts. Abnormally radioactive formations in the zone are the Coys Hill Granite, Hubbardston Granite, and Hardwick Granite of late Carboniferous or post-Carboniferous age, and the Brimfield Schist and Paxton Quartz Schist of Carboniferous age. Although the high radioactivity is fairly uniformly distributed throughout the zone, local biotite-rich pegmatitic layers at Southbridge, Worchester County, and biotite-garnet gneiss and biotite schist exposed 3 miles south of Worchester, Worchester County, are especially radioactive. Thorium was reported to be the major source of the radioactivity, but specific thorium-bearing minerals were not cited by D. H. Johnson (1951, p. 11–14). Probably very little of the radioactivity comes from monazite. Indeed, monazite may not be present, because no nearby occurrences are known in Massachusetts or Connecticut. Possibly most of the thorium is present in intergranular films or in other minerals like biotite, epidote, and apatite (Keevil and others, 1944, p. 350).

MICHIGAN

Remarkable fossil monazite placers are preserved in the Palmer area, Marquette County (Vickers, 1953, p. 203–204; 1956a, p. 173–185; 1956b; McKelvey, 1955, p. 42; Davidson, 1957, p. 674). The first indication of monazite was abnormal radioactivity observed by Robert Reed in 1951 to be associated with fragments of Goodrich Quartzite on mine dumps near Palmer. In 1952 R. C. Vickers of the U.S. Geological Survey examined the occurrences and determined that the radioactivity came from detrital monazite concentrated in the quartzite. The following summary of the geology of the fossil placers is taken from Vickers (1956a, p. 173–185).

The Palmer area is underlain by a downfaulted block of Precambrian sedimentary rocks 4 miles long and three-fourths mile wide on the south limb of the Marquette synclinorium. The fault block consists mainly of middle Huronian Ajibik Quartzite and Negaunee Iron-Formation and the unconformably overlying late Huronian Goodrich Quartzite.

Monazite occurs as brownish-red to yellow subrounded to rounded detrital grains in the matrix of layers of quartz-pebble conglomerate in Goodrich Quartzite. Most grains are 0.40–0.08 inch across. Locally they make up more than 50 percent of the matrix of the conglomerate, but usually the grains are not that abundant. Other heavy minerals in the matrix are mainly hematite, magnetite, ilmenite, and rutile.

In the lower 200 feet of the Goodrich Quartzite, the weighted average monazite content for 18 channel samples was 2.9 pounds per short ton. An isolated outcrop of pebble conglomerate more than 300 feet above the base of the formation contained 23 pounds of monazite per short ton. Glacial boulders and fragments on mine dumps, derived from even higher parts of the formation, contained from 50 to 110 pounds of monazite per short ton. From these observations it was inferred that the tenor of the layers of pebble conglomerate was greater in the parts of the Goodrich Quartzite that were 300 feet or more above the base of the formation. This inference was confirmed by the gamma-ray logging of three diamond-drill holes that penetrated a maximum apparent thickness of 1,100 feet of quartzite.

Two chemical analyses of monazite fractions, reported to contain about 92 percent of monazite, disclosed 7.6 and 7.4 percent of ThO_2, equal to 8.2 percent of ThO_2 in pure monazite:

[Analyst: Harry Levine (in Vickers, 1956a, p. 180)]

	Percent	
	A	*B*
RE_2O_3	47.9	46.0
ThO_2	7.6	7.4
U_3O_8	.2	.2
P_2O_5	19.4	19.3
SiO_2	6.9	5.7
Al_2O_3	[1] 5–10	[1] 5–10
Fe_2O_3	[1] 5–10	[1] 5–10
TiO_2	[1] 1–5	[1] 1–5
PbO	[1] 1–5	[1] 1–5
Total	94–112	91–109

[1] Spectrographic analysis.

The Palmer area contains very large tonnages of monazite that seem to have about 8 percent of ThO_2. At present there is no known deposit of equal high-thorium oxide monazite in the United States.

Elsewhere in the area of the Marquette trough there seems to be very little monazite in the Goodrich Quartzite. A few grains of monazite, however, were observed by Vickers in Goodrich Quartzite exposed about 5 miles N. 75° W. of Palmer.

Several concentrations of monazite occur in coarse arkosic quartzite that overlies and grades downward into a granite porphyry in the Gwinn district, Marquette County, 12 miles southeast of Palmer. Some of the quartzite contains as much as 9 pounds of monazite per short ton, but the concentrations are of only local extent (Vickers, 1956a, p. 185).

The relation of the composition of the monazite to the metamorphic zones in the Marquette trough is not known. Seemingly, absence of exposures might prevent satisfactory study, but if samples of monazite could be obtained from quartzite at the different metamorphic grades, a relation might be found between the grade of metamorphism, absolute abundance of monazite, and composition of monazite. It would be particularly interesting to learn if detrital monazite in quartzite reacted to metamorphism the same way that detrital monazite in pelitic sediments seems to do.

MINNESOTA

Quartz monzonite at the Myers quarry near Pierz, Morrison County, contains accessory monazite (Jaffe and others, 1959, p. 138). Monazite also occurs in the Warman Quartz Monzonite of Woyski (1949) 7 miles west of Little Falls, Morrison County, where R. G. Schmidt (oral commun., 1960) recovered 200 milligrams from 15 pounds of rock.

Monazite has been mentioned as a very rare accessory mineral in sandstone units in the St. Laurence Formation of Cambrian age exposed near Minneiska, Wabasha County (Graham, 1930, p. 710; Grim, 1936, p. 115–116).

The abundances of thorium and radium in soil at 13 places in Minnesota were determined in 1915 by J. C. Sanderson (1915, p. 397). The soils sampled were developed on boulder clay, till, drift, loess, dune sand, moraine sediment, and outwash deposits. Although the range in amount of thorium in the soils was not great, the variations were marked within the small range and were independent of the radium content. Mineral sources of the thorium radiation were not identified. Possibly the most important mineral source was allanite, which seems to be more common in the crystalline rocks of Minnesota than monazite (Winchell, 1900, p. 206, 212, 291; Sanders, 1929, p. 146).

MISSISSIPPI

SEDIMENTARY ROCKS OF EOCENE AGE

Heavy minerals in the very fine sand fraction from about 50 samples of sedimentary rocks of the Wilcox, Claiborne, and Jackson Groups of Eocene age exposed in Mississippi were studied by Grim (1936, p. 23–26), and monazite was found to be a minor accessory mineral. It was variably present in very fine sand from the Wilcox Group, present in about two-thirds of the samples from the Claiborne Group, and absent from the samples of the Jackson Group. The mineralogical composition of the 28 monazite-bearing concentrates from the Wilcox and Claiborne Groups is shown in table 54.

Lateral and vertical variation in the major components of the concentrates were not very pronounced in the sand from the Wilcox Group (Grim, 1936, p. 108–115), but there was considerable variation in the scarce minerals. Scarcity alone was interpreted to be sufficient cause for the variation. No consistent relation was found between the abundance of the heavy minerals in the very fine sand fraction and the general coarseness or fineness of the sample from which the fraction was sieved. The uniformity in the major components was interpreted to indicate that a single source area supplied the Wilcox sediments.

The dominant heavy minerals and most of the minor minerals are stable species derived originally from schist, gneiss, and granitic rocks. Minerals from mafic rocks are unimportant components of the concentrates. The absence of unstable minerals in the concentrates was interpreted by Grim to show that the sedimentary materials of the Wilcox Group had passed through more than one cycle of erosion, transportation, and deposition.

The presence of monazite and xenotime among the minor minerals in the Wilcox Group, together with the mineralogy of the dominant species in the concentrate, indicated to Grim (1936, p. 115) that the most probable ultimate source of the sediment was the Piedmont Plateau region of the southern Appalachians.

Deposition of the sedimentary rocks of the Wilcox Group in Mississippi was inferred by Grim (1936, p. 116) to have taken place in a huge delta formed by a river flowing from the northeast and entering the embayment in northeast-central Mississippi. Variable conditions on the delta gave rise to local subaerial deposits and subaqueous deposits with more marine, near-shore deposits being formed toward the southeast away from the delta.

The composition of the concentrates from the very

TABLE 54.—*Mineralogical composition of very fine monazite-bearing concentrates from sedimentary rocks of Eocene age in Mississippi*

[Modified from Grim (1936, p. 65–193). Symbols used: A, abundant; C, common; R, rare; VR, very rare; Ab, absent]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Heavy mineral concentrate (very fine sand)___ percent__	2. 74	3. 50	2. 43	1. 53	2. 8	8. 5	1. 0	3. 5	1. 7	1. 1	1. 1	5. 3	3. 1	1. 0
Ilmenite	Ab	R	R	R	C	R	C	R	R	C	C	C	C	R
Leucoxene	Ab	R	R	R	C	VR	R	VR	R	Ab	C	C	C	R
Rutile	R	A	R	C	C	C	R	R	C	C	C	C	C	C
Zircon	R	A	A	C	A	C	C	C	C	A	A	A	A	C
Garnet	Ab	Ab	Ab	Ab	Ab	Ab	VR	Ab	Ab	Ab	Ab	Ab	Ab	VR
Staurolite	C	R	A	C	C	C	C	C	C	A	A	A	A	C
Andalusite	Ab	Ab	Ab	R	Ab	Ab	Ab	Ab	VR	Ab	VR	Ab	Ab	VR
Kyanite	C	A	A	C	A	C	C	C	C	A	A	A	A	C
Sillimanite	Ab	R	R	R	VR	Ab	VR	Ab	Ab	VR	Ab	R	Ab	VR
Monazite	R	R	R	R	VR	C	VR	VR	VR	VR	VR	R	VR	VR
Xenotime	R	R	Ab	R	VR	VR	Ab	Ab	VR	VR	VR	Ab	VR	Ab
Epidote	R	R	R	R	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	VR	R
Tourmaline	R	R	A	C	C	R	C	C	C	C	C	A	A	C
Other minerals	([1] [2])	Ab	([3])	([1] [4] [5])	([6])	([7])	Ab	([8])	([9])	([10])	([11])	Ab	Ab	Ab

	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Heavy mineral concentrate (very fine sand)___ percent__	1. 0	2. 8	2. 6	3. 0	2. 9	0. 3	3. 3	1, 9	2. 7	2. 3	4. 2	1. 1	2. 1	2, 8
Ilmenite	R	R	R	R	VR	R	C	R	R	C	R	C	C	C
Leucoxene	R	R	R	R	Ab	R	C	R	R	C	R	C	C	C
Rutile	R	C	C	C	R	R	C	C	C	C	C	C	R	C
Zircon	C	C	C	C	C	C	A	C	C	A	C	C	A	A
Garnet	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	VR	VR	Ab	VR	VR	Ab
Staurolite	C	C	C	C	C	C	A	C	C	C	C	A	C	C
Andalusite	Ab	R	Ab	Ab	Ab	Ab	Ab	VR	Ab	Ab	VR	Ab	VR	VR
Kyanite	C	C	C	C	C	C	A	C	C	A	C	A	A	A
Sillimanite	C	R	R	R	Ab	R	A	R	R	VR	R	A	A	R
Monazite	R	VR	VR	VR	VR	VR	VR	VR	VR	VR	R	VR	VR	R
Kenotime	Ab	VR	VR	Ab	VR	VR	VR	VR	VR	VR	C	VR	VR	VR
Epidote	Ab	VR	Ab	VR	Ab	Ab	VR	Ab	Ab	VR	VR	VR	Ab	VR
Tourmaline	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Other minerals	([12])	Ab	Ab	([9])	([13])	([11])	([14])	Ab	Ab	Ab	Ab	([11])	Ab	Ab

[1] Rare topaz.
[2] Rare sphene.
[3] Rare biotite.
[4] Rare enstatite.
[5] Rare anatase.
[6] Very rare corundum.
[7] Very rare hornblende.
[8] Very rare spinel.
[9] Very rare fluorite.
[10] Very rare topaz.
[11] Very rare zoisite.
[12] Very rare anatase.
[13] Common pyrite.
[14] Very rare sphene.

Wilcox Group:
- Deltaic:
  1. 10 miles east of Oxford.
  2. 0.5 mile south of Oxford.
- Littoral:
  3. 2 miles east of Grenada.
  4. 2 miles northeast of Marion.

Wilcox to Claiborne transition—neritic or littoral:
5. 7 miles southeast of Duck Hill.

Claiborne Group:
- Meridian Member:
  - Neritic:
    6–7. 5 miles east of Zama.
    8. 18 miles east of Kosciusko.
  - Neritic or littoral:
    9. 19 miles east of Kosciusko.
- Winona Member:
  - Neritic:
    10. 0.25 mile east of Zama.
    11. 23 miles north of Kosciusko.
  - Neritic or littoral:
    12. Meridian-Paulding road 3 miles south of Meridian-Jackson highway.
    13. Poplar Creek road 5 miles north of Kosciusko-Vaiden road.

Claiborne Group—Continued
- Littoral:
  14. 3 miles west of Winona.
- Kosciusko Member—neritic or littoral:
  15. 2 miles south of Enterprise.
  16. Meridian-Paulding road 5 miles south of Meridian-Jackson highway.
  17. South edge of Kosciusko.
  18. 12 miles west of Kosciusko.
- Chickasawhay Member:
  - Neritic:
    19. 1.5 miles north of Stonewall.
    20. 4 miles north of Newton.
    21. 4.5 miles east of Walnut Grove.
  - Neritic or littoral:
    22. 4 miles north of Carthage.
    23. 7 miles southwest of Thomastown.
    24. Big Black River at bridge on Kosciusko-Durant highway.
    25. 4 miles east of Lexington.
- Yegua Formation—neritic or littoral:
  26. 2 miles south of Newton.
  27. 0.5 mile north of Harperville.
  28. 0.25 mile east of the Pickens-Canton highway just south of the Big Black River.

fine sand fraction of the sedimentary rocks in the Claiborne Group is very constant, and monazite was present in two-thirds of the samples. The dominant minerals are persistent laterally and vertically, and the abundance of heavy minerals is seemingly unrelated to the coarseness or fineness of the sediment (Grim, 1936, p. 201–207). Similar heavy minerals having similar characteristics, except degree of rounding, are present in the Claiborne and Wilcox Groups, which probably means that the sedimentary materials in both groups came from the same ultimate source areas in the Piedmont. The proximate source, however, was apparently older sedimentary rocks of the Coastal Plain, because the heavy minerals in the Claiborne Group are more rounded than those in the Wilcox. Other characteristics of the sedimentary rocks of the Claiborne Group were interpreted by Grim (1936, p. 214) as showing that the rocks are of littoral or neritic origin, that they extended across the site of the Wilcox delta, and that they were deposited from many streams instead of one major stream.

These relations are interpreted by the writer as indicating that the likelihood of fossil placers is greater in the Claiborne than in the Wilcox, because reworked beach deposits are probably more common in the Claiborne. As yet no placer has been reported.

SURFICIAL, FLUVIAL, AND BEACH DEPOSITS

Surficial deposits on the Tom Davis farm near Columbia, Marion County, were reported to contain a little gold and traces of thorium-bearing minerals (Mining World, 1949). The gold was said to be in blue clay and the thorium-bearing mineral in gravel. Doubtless the reported occurrence is detrital monazite. Although the geology of the deposit is not described, it should be noted that the locality is near the present channel of the Pearl River which extends northward into the monazite-bearing sedimentary rocks of Eocene age around Carthage, Leake County.

All 13 samples of sediment from the present bed of the Mississippi River at Greenville in Washington County, Vicksburg in Warren County, and Natchez in Adams County were reported to contain less than 1 percent of monazite in the concentrate (Russell, 1937, p. 1316–1325).

Beach sand on the shores and barrier islands of Mississippi Sound as far west as Cat Island, Harrison County, contains minor accessory monazite and hornblende (Harding, 1960; Hahn, A. D., 1962, p. 1). Common heavy minerals are ilmenite, kyanite, rutile, staurolite, tourmaline, and zircon. The suites of heavy minerals are similar throughout the area sampled owing probably to a common source for the sedimentary material. Local variation in the degree of concentration of the heavy minerals in the beach sand was interpreted by Harding to result from littoral drift toward the southwest with variable reworking of nearshore and bottom sediments. An analysis of a concentrate from Cat Island was given by Dohm (1936, p. 378–379) and is listed in table 53 in the section under Louisiana.

Fine-grained ilmenite, rutile, zircon, kyanite, staurolite, tourmaline, and monazite occur in beach and dune sand on Ship Island, a barrier island 7 miles long and 1,000–3,600 feet wide separated from the mainland part of Harrison County by the Mississippi Sound (Hahn, 1962, p. 2–6). The heavy minerals form either bedded concentrations as much as 5 inches thick, 15 feet wide, and 100 or more feet long, or they occur as disseminated grains which lend a mottled appearance to the sand. Concentrates from less than 35-mesh fraction of the sand were said to have the following composition (Hahn, 1962, p. 6):

	Percent
Ilmenite, leucoxene, rutile	41
Zircon	10
Kyanite	25
Staurolite, tourmaline	23.7
Monazite	.3
Total	100.0

The principal source of the heavy minerals are sediments discharged at the gulf coast by streams reaching to the crystalline rocks of the Appalachians and transported along the coast by littoral drift. In 1961 the heavy-mineral deposits on Ship Island were drilled by the U.S. Bureau of Mines, and only the western part of the island was found to have enough ilmenite and monazite to be classed as a possible source of these minerals (Hahn, 1962, p. 16, 23, 24):

Part of island	Area (acres)	Average thickness of sand (feet)	Weight of sand (million short tons)	Heavy minerals (percent)	Reserves (short tons)	
					Ilmenite	Monazite
Eastern	779	15.0	25	1.97		
Western	665	7.7	11	5.93	209,000	800

MONTANA

The earliest reports of monazite in Montana were by Day (1905a, p. 9) and Day and Richards (1906b, p. 1202–1203) and were on placer concentrates from streams in Granite County and Powell County. During the 1950's other workers discovered several radioactive occurrences in crystalline and sedimentary rocks in Montana, and the unusual radioactivity was locally attributed to thorium. Most of these thorium occurrences do not contain monazite. Few monazite deposits occur in the crystalline rocks in the State, but large monazite-bearing fossil placers are present in sedimentary rocks of Late Cretaceous age.

CRYSTALLINE ROCKS

Carbonatite containing columbite, monazite, and ancylite (M. H. Staatz, written commun., 1963) forms a dike in fine-grained gneiss of undescribed composition on Sheep Creek, a northward-flowing tributary of the West Fork of Bitterroot River in Ravalli County (Sahinen, 1957, p. 53–54). Vermiculite and altered biotite are present in the carbonatite, and hornblende gneiss is exposed near the deposit. A little prospecting was done about 1955, and the carbonatite was found to be 5 or 6 feet thick in a vertical exposure of 12 feet and to dip steeply northeastward to vertical. The monazite occurs as yellow grains in crystals of columbite. Apparently not much monazite is present, and what is there may be low in thorium because thorium was not detected in analyses of mixtures of columbite and ancylite.

The thorium occurrences in the Lemhi Pass area extend across the State line from Beaverhead County, Mont., into Idaho. They are described in the section on "Idaho."

Monazite occurs as a minor accessory mineral in porphyritic biotite-muscovite granodiorite and gneissic granodiorite exposed at Lost Horse Creek near Hamilton, Ravalli County (Jaffe and others, 1959, p. 78–79). These writers (p. 80–81) also reported accessory monazite in alaskite at an exposure about 0.5 mile southwest of the summit of Elkhorn Peak, Jefferson County.

The Deer Creek district, Beaverhead County is a north-trending area 26 miles long and 12 miles wide west of Dell and south of Armstead where radioactive deposits were found in the early 1950's (Trites and Tooker, 1953, p. 184–191; Jarrard, 1957, p. 48). Some of the deposits contain monazite. The district is underlain by gneiss and schist of Precambrian age which are cut by dikes of Precambrian pegmatite and is surrounded by shale and limestone of Carboniferous age. Cutting these rocks are stocks and dikes of Tertiary igneous rocks and locally overlying them are volcanic rocks of Tertiary age. Tertiary lake deposits and younger sediments fill the large valleys.

Accessory monazite is present at Limekiln Canyon in the Deer Creek district in five small pegmatite dikes of which the largest is 9 feet wide and 23 feet long (Trites and Tooker, 1953, p. 184). Three similar dikes as much as 75 feet in length exposed about half a mile north of Limekiln Canyon and another pegmatite about a quarter mile to the south of the canyon also contain minor accessory monazite.

Diorite pegmatite dikes exposed between the North Fork of Deer Creek and Bell Canyon contain accessory monazite and allanite. The monazite may be rich in thorium oxide, because spectrographic analyses of the mineral show thorium, cesium, and phosphorus as major constituents, lanthanum and silicon as minor constituents, and yttrium, calcium, magnesium, and lead as trace constituents (Trites and Tooker, 1953, p. 187), but chemical analyses for thorium oxide have not been reported. Some biotite-rich parts of contact-metamorphic zones adjacent to the dikes are unusually radioactive, probably owing to monazite disseminated in the altered zones.

Elsewhere in Montana, monazite seems to be unreported from granitic pegmatites although allanite is very common (Heinrich, 1949, p. 29–32).

FOSSIL PLACERS

Ilmenite-bearing fossil placers in sandstone of Late Cretaceous age were discovered in 1911 and 1912 by Stebinger (1914, p. 329) in northwestern Montana. Stebinger's account of the placers does not specifically mention monazite as one of the detrital minerals, and even as late as 1946 a report on the detailed examination of a fossil placer in Teton County did not disclose monazite (Wimmler, 1946, p. 4). The search for radioactive materials in the 1950's, however, showed that many of the fossil placers contain small amounts of monazite and other radioactive minerals (Murphy and Houston, 1955, p. 190, 192).

The fossil placers in Montana are part of a band of like deposits that occur discontinuously in sandstone formations of Late Cretaceous age exposed along the east front of the Rocky Mountains from the border between Montana and Canada through Wyoming and Colorado into New Mexico. In Montana the fossil placers occur in the Virgelle Sandstone Member, the Horsethief Sandstone, and the St. Mary River Formation (Murphy and Houston, 1955, p. 190; Armstrong, 1957b, p. 215). Most of the fossil placers are beach deposits formed at the transition between marine and nonmarine sediments, but the placers in the St. Mary River Formation are 800–900 feet above the highest marine fossils and are probably stream or estuarine deposits (Murphy and Houston, 1955, p. 190). In most areas fossil placers occur in several stratigraphic horizons. Apparently these deposits represent successive retreats and advances of the sea.

Individual fossil placers are elongate and lenticular and are not persistent for long distances (Murphy and

Houston, 1955, p. 190). Their actual size is rarely determinable from the outcrops. Most are less than 4 miles long and 5 feet thick. A placer was drilled at the Devils Basin about 20 miles north of Roundup, Musselshell County, and the thorium-bearing parts were found to be from 2 to 10 feet thick (Jarrard, 1957, p. 50). Inasmuch as they tend to be narrow and elongate like black sand deposits on present beaches, most of the fossil placers are probably no wider than 1,000 feet, and many may be much smaller.

The fossil placers are well cemented by hematite and carbonate minerals and are more resistant to erosion than beds in the same sequence that lack concentrations of heavy minerals. For the most part, the sandstones in which the placers occur are coarse grained, gray, cross-bedded, and massive and are composed chiefly of quartz and altered feldspar (Stebinger, 1914, p. 330; Armstrong, 1957b, p. 215). The heavy minerals in the fossil placers consist of common ilmenite, anatase, magnetite, and zircon, less common garnet and rutile, and sparse monazite, tourmaline, epidote, staurolite, spinel, ilmenorutile, and sphene. Monazite makes up less than 1 percent of the heavy minerals in the fossil placers. The unusual radioactivity of the placers probably comes mainly from zircon.

The principal areas of monazite-bearing titaniferous fossil placers in Montana are in a belt defined approximately by Choteau in Teton County on the northwest, Great Falls in Cascade County on the northeast, Harlowton in Wheatland County on the southwest, and Roundup in Musselshell County on the southeast (Jarrard, 1957, p. 49–50). Monazite-bearing placers have been listed at eight localities in the vicinity of Choteau (Murphy and Houston, 1955, p. 195). Northwest of the main area, monazite-bearing fossil placers occur at three localities near Cut Bank, Glacier County (Murphy and Houston, 1955, p. 195).

Substantial tonnages of monazite seem to be present in these fossil placers, but the indicated tenor—less than 1 percent of monazite in the concentrate—of the few deposits that have been evaluated shows that the monazite could be recovered only as a coproduct with the titaniferuos minerals and zircon, neither of which can be mined under technological conditions of 1962.

PRESENT STREAM PLACERS

Magnetite-rich monazite-bearing concentrates from recent placers were described by Day and Richards (1906b, p. 1202–1203) from Princeton in Granite County and from an unspecified locality in Powell County. Later the occurrence at Princeton was described as a monazite-bearing natural black sand placer of unknown extent (Rowe, 1928, p. 818; Waldron and Earhart, 1942, p. 179). The occurrence in Powell County has not been further described, but the original account stated that the concentrate came from sand containing only 3 pounds of heavy minerals per cubic yard. As reported by Day and Richards, the composition of the concentrates from the two counties was as follows:

	Pounds per short ton	
	Granite County	*Powell County*
Magnetite	1, 952	1, 779
Chromite	------	17
Ilmenite	10	-------
Garnet	------	128
Monazite	6	16. 3
Zircon	------	8
Undetermined	32	-------
Total	2, 000	1, 948. 3

Gold and platinum were present in the concentrate from Granite County, and gold was present in the one from Powell County.

Monazite also occurs in Little Gold Creek in Granite County (Lyden, 1948, p. 41). The stream is a tributary of Boulder Creek. Gravel from Little Gold Creek was reported by Lyden to contain about 5 pounds of concentrate per cubic yard, and the concentrate consists of ilmenite, wolframite, and monazite and very sparse gold and platinum.

Monazite-bearing stream placers at Victor and McCalla and in Rye Creek in Ravalli County were explored by the U.S. Bureau of Mines in the early 1950's, but the results of the investigations were not published (Eilertsen and Lamb, 1956, p. 12). Apparently the deposits in the Victor and McCalla area have fairly large volume and fairly high tenor, and the monazite contains 6 percent of ThO_2 and 0.52 percent of U_3O_8 (Kauffman and Baber, 1956, p. 6, 10).

Monazite placers occur along Trail Creek in Beaverhead County (Eilertsen and Lamb, 1956, p. 12), but apparently they are neither as large as nor have as high a grade as those in the Victor and McCalla area. Monazite from the Trail Creek placers contains 4.10 percent of ThO_2 and 0.10 percent of U_3O_8 (Kauffman and Baber, 1956, p. 6).

Placers at Price and Powder Gulch in Silver Bow County contain monazite, but details were not published (Eilertsen and Lamb, 1956, p. 12).

Stream concentrates from Madison County were reported to contain monazite as early as 1905 (Day, 1905a, p. 9). In 1907, monazite associated with small amounts of thorianite, xenotime, zircon, and spinel and considerable amounts of magnetite, ilmenite, and garnet was discovered at Norris, Madison County, in a stream placer in an area underlain by granite gneiss

(Sterrett, 1908a, p. 791). The monazite-bearing placer concentrate examined by Day may have come from the Norris area, but the way the discovery in 1907 was described it seems likely that it is from a different locality. Subsequent accounts, however, mentioned only the monazite from Norris in descriptions of the minerals in Madison County (Rowe, 1928, p. 818; Waldron and Earhart, 1942, p. 179, 199).

NEBRASKA

Two 2,000-pound samples of sand from Milford in Seward County, were reported by Day and Richards (1906b, p. 1202–1203) to contain a trace each of monazite. The source of the sand was not described.

NEVADA

Granite augen gneiss near Mesquite in Clark County was reported to contain as much as 2 percent of monazite and 5 percent of xenotime in individual samples (Young and Sims, 1961, p. 274). The deposit was said by M. H. Staatz (written commun., 1963) to be across the State line in Mohave County, Ariz. Other accessory minerals in the gneiss are sparse hornblende, limonite, magnetite, zircon, and allanite(?). The size and average tenor of the occurrence has not been evaluated. Minor occurrences of monazite in Clark County have been reported (Mineralogist, 1950) in the Clark Mountain and Crescent Peak areas, where the monazite is associated with bastnaesite in granite gneiss, and in the Gold Butte mining district, where monazite is doubtfully present in biotite pegmatite of Precambrian(?) age (Lovering, 1954, p. 80).

Two auriferous concentrates from placers in the vicinity of Carson City, Ormsby County, were found by Day and Richards (1906b, p. 1204–1205; Lincoln, 1923, p. 279) to contain the following amounts of monazite:

	Pounds per short ton	
	A	*B*
Magnetite	1, 387	1, 190
Chromite	485	168
Garnet	41	353
Monazite	29	5
Zircon	21	80
Quartz	9	5
Total	1, 972	1, 801

Specific sources for these concentrates were not cited, but *B* was described as coming from alluvium(?) containing 12 pounds of black sand per ton.

NEW HAMPSHIRE

The only described occurrences of monazite in New Hampshire are localities where monazite is present as a minor accessory mineral in crystalline rocks. Monazite was first reported in 1892 in gneiss at Randolph in Coos County and at Wakefield in Carroll County, and possible accessory monazite in oligoclase gneiss was reported at Swanzey in Cheshire County (Derby, 1891a, p. 205; Am. Naturalist, 1892). In the 1940's and 1950's several monazite localities were reported by M. P. Billings and others in detailed studies of the geology of the State. The distribution of these localities and the modes of occurrence of the monazite are closely related to the regional geology.

New Hampshire is underlain by sedimentary and volcanic rocks that range in age from Ordovician(?) to Mississippian(?) (Billings, 1956, p. 5–6). Devonian and older sedimentary and volcanic rocks have been regionally metamorphosed to the greenschist, albite-epidote-amphibolite, and amphibolite facies. Volcanic rocks of Mississippian(?) age were not involved in the regional metamorphism, but they have been slightly affected by contact metamorphism. The metasedimentary rocks are folded into a major northeast-trending synclinorium which occupies most of the State and in which the rocks are of the upper subfacies of the amphibolite facies. Flanking the central synclinorium is an anticlinorium in the southeastern part of the State and an anticline adjacent to the State lines of Vermont and Connecticut. In these anticlinal structural features the grade of the metamorphism declines to the greenschist facies. Emplaced in the metamorphic rocks are seven groups of plutonic rocks of which the oldest is probably Precambrian or early Paleozoic in age and the youngest is probably Mississippian(?) in age (Billings, 1956, p. 5–6).

Among the metasedimentary and metavolcanic rocks, monazite has only been reported from the Early Devonian Littleton Formation where this unit has been metamorphosed to the middle and upper subfacies of the amphibolite facies. In a study of the minor accessory minerals in the rocks of the Lovewell Mountain and Keene quadrangles, Heald (1950, p. 44, 68) found that six out of seven samples of sillimanite schist and quartz-mica schist contained small amounts of monazite (table 55). Allanite, which is an especially common mineral in the lower grade metasedimentary and metavolcanic rocks and in retrogressively metamorphosed plutonic rocks (Billings and Keevil, 1946, p. 801–810; Gottfried, 1954, p. 204–205), is not present in the high-grade gneisses sampled in the Lovewell Mountain and Keene quadrangles. The Keene quadrangle includes Swanzey where Derby (1891a, p. 205) reported monazite.

Among the seven groups of plutonic rocks recognized in New Hampshire, only a few members of the New Hampshire Plutonic Series are monazite bear-

TABLE 55.—*Mineralogical composition, in weight percent, of heavy-mineral fraction of the rock, in the Lovewell Mountain and Keene quadrangles, New Hampshire*

[Modified from Heald (1950, p. 68). Symbol used: Tr., trace]

	1	2	3	4	5	6	7	8
Biotite	12	27	31	14	17	16	19	8
Garnet	.3	.8	6	2	.05	2	.3	.4
Sillimanite	.0	1	1	4	Tr.	.03	.0	.03
Kyanite	.0	Tr.	.4	.01	.0	Tr.	.0	.0
Tourmaline	.02	.5	.0	.0	Tr.	.0	.0	.0
Chlorite	.0	.0	.0	2	.0	.1	.0	.0
Apatite	.03	.05	.8	.1	.2	.1	.03	.03
Zircon	.002	.008	.004	.008	.003	.05	.01	.02
Monazite	.002	.002	.0	.004	.005	.02	.002	.009
Sphene	.0	.005	Tr.	.02	.04	.1	.0	.04
Magnetite	.06	.07	1	.5	.1	1	.03	.1
Pyrite	.0	.0	.0	2	.05	.1	.0	.0
Opaque minerals	.3	.3	.5	.2	.2	.3	.2	.3

1. Littleton Formation, average of 2 specimens of mica schist from middle-grade zone, Keene area to the southwest of the Lovewell Mountain quad.
2. Littleton Formation, average of 2 specimens of mica-quartz schist from high-grade zone.
3. Littleton Formation, biotite gneiss from high-grade zone.
4. Littleton Formation, average of 2 specimens of pyritiferous gneiss from high-grade zone.
5. Bethlehem Gneiss.
6. Kinsman Quartz Monzonite, average of 3 specimens from Bacon Ledge pluton.
7. Kinsman Quartz Monzonite, small pod in schist.
8. Granodiorite from late dikes, average of 2 specimens.

ing, and they only contain monazite where they are emplaced in high-grade metasedimentary rocks. The Bethlehem Gneiss, Kinsman Quartz Monzonite, and granodiorite of the New Hampshire Plutonic Series contain from 0.004 to 0.02 percent of monazite (table 55) in the Lovewell Mountain quadrangle (Heald, 1950, p. 68). Bethlehem Gneiss in the Bellows Falls quadrangle in Cheshire and Sullivan Counties (Kruger, 1946, p. 183), the Sunapee quadrangle in Sullivan and Merrimack Counties (Lyons and others, 1957, p. 533), and the Moosilauke quadrangle in Grafton County (Billings and Keevil, 1946, p. 810–813) contains accessory monazite. Concord Granite and associated pegmatite of the New Hampshire Plutonic Series contains monazite in the Cardigan quadrangle, Grafton and Merrimack Counties (Lyons and others, 1957, p. 533; Morrill, 1960, p. 18; Cameron and others, 1954, p. 1).

The monazite reported by Derby (1891a, p. 205) at Wakefield is probably from sillimanite-grade gneiss of the Littleton Formation, but its source is uncertain. The monazite from the vicinity of Randolph is possibly from a similar, but also uncertain, source.

Analyses of the uranium and estimates of the thorium in monazite from the Kinsman Quartz Monzonite, Bethlehem Gneiss, and Concord Granite were made by Lyons, Jaffe, Gottfried, and Waring (1957, p. 533). The abundance of thorium was estimated according to the equation:

$$\alpha = 0.366 \text{ U} + 0.0869 \text{ Th}$$

where α is alpha activity per milligram per hour, U is the uranium content in parts per million, and Th is the thorium content in parts per million (Lyons and others, 1957, p. 529). Converting the published results from parts per million of U and Th to percentages of U_3O_8 and ThO_2, the measured abundance of U_3O_8 and estimated abundance of ThO_2 in the monazite are:

Rock	Quadrangle	U_3O_8 (measured)	ThO_2 (estimated)
		Percent	
Kinsman Quartz Monzonite.	Lovewell Mountain.	0.16	5.06
Bethlehem Gneiss	Sunapee	.30	2.48
Concord Granite	Cardigan	.07	3.25

The indicated abundances of thorium oxide for the monazite from the Bethlehem Gneiss and Concord Granite are about half as great as the abundance commonly found in monazite from plutonic rocks associated with rocks of the sillimanite-almandine subfacies, but the indicated abundance of thorium oxide in monazite from the Kinsman Quartz Monzonite is very typical of monazite associated with rocks of this metamorphic grade.

The absence of monazite from the Oliverian and Highlandcroft Plutonic Series, which are older than the New Hampshire Plutonic Series, may relate to the low-grade metamorphism which affected those rocks but not the younger series (Lyons and others, 1957, p. 529). Allanite, epidote, and sphene are particularly common in the low-grade metamorphosed plutonic rocks but are rare in the New Hampshire Series.

Monazite seems to be absent from the thorium oxide-rich White Mountain Plutonic Series (Billings and Keevil, 1946, p. 801–810). The rocks are Mississippian(?) in age and include both intrusive and extrusive phases. Allanite and sphene are common accessory minerals. Monazite is found in apparently equivalent rocks at Ascutney Mountain, Vt., in which primary allanite mantles the monazite. Possibly the mantles of allanite indicate that monazite is unstable where the magma reaches hypabyssal or effusive environment and that reaction between earlier formed monazite and magma give allanite as one product. The general presence of allanite and absence of monazite in the series might then be related to this reaction.

NEW JERSEY

The Canfield phosphate mine 2 miles west of Dover, Morris County, contains a granular aggregate of magnetite and apatite with which are associated small amounts of quartz, feldspar, and biotite and very sparse monazite (McKeown and Klemic, 1953, p. 19–20, 58). Monazite and zircon were reported to form most of a rust-brown rock near Chester and Tanners

Brook in Morris County (Markewicz and others, 1957). Dense fine-grained reddish-brown monazite from the Chester area was reported by Molloy (1959, p. 510) to have been analyzed by Ledoux and Co. of Teaneck, N.J., the monazite was found to contain 13.66 percent of ThO_2, 53.36 percent of RE_2O_3, 25.31 percent of P_2O_5, and 0.045 percent of U_3O_8. The monazite is cut by nonradioactive quartz veins and, at the time of this writing, had not been found in place but occurred as fragments in residuum containing fractured blocks of quartz-feldspar granite.

A crystal of monazite was found in pegmatite float at the Ringwood mines about 4 miles east of the south end of Greenwood Lake at Ringwood, Passiac County. Biotite-rich phases of the Byram Granite Gneiss locally contain noticeable amounts of monazite at West Milford near Ringwood (Markewicz and others, 1957). Quartz-feldspar pegmatite exposed on the Poronowicz farm at the northwest edge of the village of Oxford Furnace, Warren County, contains sparse magnetite and monazite (McKeown and Klemic, 1953, p. 49, 60).

Ilmenite sands in the Cohansey Formation of Pliocene(?) age, the Kirkwood Formation of Miocene age, and the Cape May Formation of Pleistocene age in Ocean and Burlington Counties in southern New Jersey contain very small amounts of monazite (Markewicz and Parrillo, 1957; Markewicz and others, 1958, p. 6–8). The fossil placers occur in stream channels in the Cohansey Formation and in marine deposits in the Kirkwood and Cape May Formations. Samples from 200 auger holes disclose that the sand contains an average of 3 percent of heavy minerals. Illmenite, rutile, and zircon make up about 85–98 percent of the concentrate. Associated with them are anatase, leucoxene, staurolite, kyanite, sillimanite, tourmaline, andalusite, amphibole, hypersthene, garnet, epidote, monazite and sparse glauconite. At most places these minerals never amount to more than 1 or 2 percent individually, and commonly they totaled less than 2 percent of the concentrate.

Ordinary sands from the Cape May Formation apparently contain just a trace of monazite. Out of nine samples from the Cape May Formation examined by McMaster (1954, p. 62–170) in a study of the beach sands of New Jersey, only two contained even a trace of monazite (table 56). These samples came from West End, Monmouth County, and Highbee Beach, Cape May County.

Of 39 beach sand samples for which mineral analyses were given by McMaster (1954, p. 62–170), 9 contain monazite, and of the 15 sea-bottom samples for which analyses are given 7 are monazite bearing (table 56). Ordinarily the monazite is merely a trace in the medium or finest grain sizes, but in several samples from each environment it appears in the coarse sizes (table 56). The distribution of the monazite-bearing beach sand is fairly regular southward on the coast and does not seem to be related to the geomorphic form of the beach. Thus, it is present in beach sand on the spit and bay bar at and south of Sandy Hook, Monmouth County; in beach sand on the barrier bars as at Seaside Park, Island Beach, and Surf City, Ocean County; and in sand on beaches formed on the mainland at Cape May (McMaster, 1954, p. 1–2). Concentrations of monazite were not found on the beaches, presumably because the source materials from which the beaches were formed were so lean in monazite.

NEW MEXICO

The first reported occurrences of monazite in New Mexico were in sand associated with gold placers, the most frequently mentioned occurrences are in pegmatite dikes, and the economically most favorable occurrences are in fossil placers in Upper Cretaceous sandstone. Large resources of monazite seem to be present in the fossil placers.

CRYSTALLINE ROCKS

The Petaca Mountains pegmatite district, including the Tunas Mountains, Rio Arriba Mountains, and the Ojo Caliente district in Rio Arriba County have been the source of museum specimens of euhedral and massive monazite (Hess and Wells, 1930, p. 19; Just, 1937, p. 18; Jahns, 1946, p. 64, 66; Palache and others, 1951, p. 695; Anderson, E. C., 1957, p. 106, 161) and may have been the source of the samples of monazite from New Mexico examined by the U.S. Bureau of Mines in 1922 (Queensland Govt. Mining Jour., 1922, p. 247). The Petaca district is a belt of pegmatites in Precambrian metamorphic and igneous rocks that extends northwestward 40 miles from Ojo Caliente to the west end of Jawbone Mountain (Just, 1937, p. 40–48; Jahns, 1946). At its greatest width the belt is 9 miles wide. The Precambrian rocks consist of feldspathic hornblende-chlorite schist formed through the metamorphism of flows of basalt and andesite, with which are associated schistose rhyolite and trachyte, conglomerate, quartzite, and quartz-muscovite schist. These rocks are extensively epidotized and silicified, particularly in contact zones adjacent to masses of granite. The granite varies widely in texture but is generally medium grained, nonporphyritic, and granulated. It also varies widely in composition; where ferromagnesian minerals are lacking, it is pink but where biotite is present, it is gray. Aplite dikes and quartz veins are present in the metamorphic rocks near the granite.

Pegmatite dikes in the Petaca district are small, and they have irregular shape, simple mineralogical

TABLE 56.—*Mineralogical composition, in frequency percent, of heavy-mineral fraction of monazite-bearing concentrates from coastal sediments of New Jersey*

[Modified from McMaster (1954, p. 62–170). Symbol used: Tr., trace; --, absent]

	Beach sediments										Ocean-bottom sediments								Source sediments			
	[1] 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Size of monazite-bearing fraction..........mm..	0.105	0.105	0.105	0.149	0.105	0.074	0.149	0.074	0.149	0.210	0.210	0.149	0.210	0.149	0.105	0.074	0.149	0.149	0.210	0.105	0.210	0.149
Heavy minerals in size grade..weight percent..	34.0	40.0	83.7	20.1	53.0	5.6	16.8	80.0	1.5	0.2	0.7	9.2	0.4	2.9	14.1	58.5	35.3	2.1	0.7	7.0	0.8	1.0
Andalusite	0.8	1.2	Tr.	2.1	--	Tr.	Tr.	--	0.5	0.9	1	1	1	Tr.	1	--	--	1	4	Tr.	1	2
Apatite	--	--	--	--	--	Tr.	--	0.9	.5	.9	--	Tr.	--	--	1	2	Tr.	--	--	Tr.	1	--
Chlorite	--	--	--	--	--	--	--	--	1.0	7.5	1	--	1	1	--	--	Tr.	3	3	--	--	2
Diopside	1.0	1.2	1.2	.9	0.7	Tr.	1.1	1.6	6.4	5.3	2	3	4	2	1	1	1	1	Tr.	1	1	Tr.
Epidote	1.6	1.8	.9	--	1.4	4.8	.5	6.0	2.4	2.8	Tr.	1	Tr.	1	3	6	--	3	1	2	Tr.	1
Garnet	5.6	6.2	10.7	7.5	7.2	7.7	6.2	13.4	6.7	10.0	18	10	7	9	11	17	7	6	1	13	11	3
Glauconite	1.6	2.1	1.5	1.5	Tr.	--	--	--	--	Tr.	3	6	--	Tr.	--	--	--	--	11	3	--	--
Hornblende	2.4	5.9	2.4	6.9	5.7	13.4	12.4	35.2	43.6	31.2	23	19	6	9	27	36	3	18	2	20	1	2
Hypersthene	1.3	1.2	.6	2.7	Tr.	.8	1.1	4.6	2.9	5.9	3	3	1	1	4	4	Tr.	1	Tr.	4	1	1
Kyanite	1.0	1.5	.9	1.2	Tr.	--	.8	.5	.7	.9	2	3	1	Tr.	Tr.	Tr.	1	1	3	4	2	--
Muscovite	--	--	--	--	--	--	--	--	Tr.	6.9	1	--	1	--	--	--	--	--	3	Tr.	1	1
Rutile	1.6	1.5	.9	Tr.	1.0	1.6	.5	Tr.	--	--	--	Tr.	--	--	--	Tr.	1	--	--	Tr.	Tr.	1
Sillimanite	Tr.	--	.6	Tr.	Tr.	Tr.	1.9	.5	3.0	2.8	Tr.	2	2	2	2	1	1	2	4	1	3	4
Staurolite	4.0	3.3	2.4	8.7	1.4	Tr.	6.2	.7	2.0	.6	5	10	7	4	1	1	3	3	11	8	13	6
Sphene	1.0	1.2	Tr.	--	--	1.6	Tr.	.9	.5	.9	--	--	--	Tr.	1	1	Tr.	Tr.	--	Tr.	--	--
Tourmaline	.8	1.8	--	2.1	Tr.	Tr.	3.2	Tr.	.5	1.2	1	2	10	4	1	--	1	2	22	1	11	5
Tremolite	--	--	--	--	--	Tr.	--	.5	1.7	.6	1	Tr.	Tr.	--	Tr.	Tr.	--	1	--	Tr.	--	Tr.
Zircon	7.2	7.7	9.4	.6	9.9	20.9	1.6	3.5	--	1.9	--	1	1	3	5	5	5	2	--	6	1	5
Augite	--	--	--	--	--	--	--	.5	--	--	Tr.	3	1	--	--	--	1	Tr.	--	--	--	--
Chloritoid	.5	--	Tr.	Tr.	Tr.	Tr.	--	.5	.5	Tr.	--	1	--	--	--	1	--	Tr.	1	1	Tr.	--
Collophane	Tr.	.6	--	--	--	--	--	--	--	--	--	--	--	Tr.	--	--	--	--	--	--	--	--
Monazite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	1	1	Tr.	Tr.	Tr.	Tr.
Zoisite	--	Tr.	--	--	Tr.	Tr.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Biotite	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Black opaque minerals	65.6	57.0	65.5	62.2	65.8	43.0	58.8	26.2	12.0	12.7	16	26	44	53	36	18	71	43	7	27	46	60
Leucoxene	1.9	1.8	1.8	.9	2.5	1.6	2.4	.9	2.6	4.0	2	2	4	2	1	1	2	3	13	2	3	4
Shell fragments, composite, altered and unknown grains	2.0	4.0	2.0	1.8	2.0	2.0	3.0	3.6	12.4	3.0	20	6	8	8	5	5	3	8	13	4	5	2

1. Fort Hancock, Monmouth County.
2. Asbury Park, Monmouth County.
3. Seaside Park, Ocean County.
4. 0.8 mile south of Coast Guard Station, Island Beach, Ocean County.
5, 6. Surf City, Ocean County.
7. 0.3 mile south of north point of Tucker Island, Ocean County.
8. Brigantine, Atlantic County.
9. 0.9 mile north of Ludlum Beach Light, Sea Island City, Cape May County.
10. Wildwood, Cape May County.
11. New York Bay 3 miles north of Sandy Hook, Monmouth County.
12. Atlantic Ocean 1.6 miles northeast of Sandy Hook, Monmouth County.
13. Little Egg Inlet, Ocean County.
14, 15. Atlantic Ocean 0.8 mile off Little Egg Inlet, Ocean County.
16. Atlantic Ocean 1.7 miles off Little Egg Inlet, Ocean County.
17. Atlantic Ocean 1.5 miles off Little Egg Inlet, Ocean County.
18. Atlantic Ocean 5 miles southeast of Cape May, Cape May County.
19, 20. Cape May Formation at West End, Monmouth County.
21, 22. Cape May Formation exposed at Higbee Beach, Cape May County.

composition, and homogeneous structure where they occur in the granite. Dikes in the metamorphic rocks are parallel to the strike of the foliation but transgressive to the dip; they are mica rich and of complex mineralogy. Most concentrations of fluorite, columbite, monazite, beryl, and samarskite occur in the dikes in the metamorphic rocks. Monazite is a common minor constituent of albite-rich parts of the pegmatites (Jahns, 1946, p. 64). It occurs as well-developed flattened crystals, as coarse crystals and equant masses weighing as much as 10 pounds, and as thin tabular and elongate crystals. The monazite is light to dark brown, and feldspar surrounding the monazite is commonly stained yellowish brown to deep brick red. Large monazite crystals are fresh, but some thin tabular ones are altered to brown earthy powder (Jahns, 1946, p. 65). The specific gravity of monazite from the Petaca district is 5.0 (Northrop, 1944, p. 219). The monazite in the pegmatites of the Petaca district is a minor accessory mineral that cannot be commercially exploited, although a small market once existed for museum specimens.

Monazite-bearing pegmatites in the district have been individually mentioned as occurring in the Fridlund, Cribbensville, Silver Spur, North Star, Freetland, Coats, Pinto Verde, Globe, Alamos, Apache, Nambe, and Capitan deposits (Hess and Wells, 1930, p. 17; Just, 1937, p. 63–64; Northrop, 1944, p. 219; Jahns, 1946, p. 64–65).

Several chemical analyses have been made of monazite from the Petaca district, and material doubtfully from the Petaca district has been analyzed. The first of these analyses, and the one for which the location is doubtful, is of a crystal collected by P. Krieger and sent by A. C. Lane in 1935 to Friedrich Hecht and Edith Kroupa in Vienna for microchemical analysis (Lane, 1935, p. 19, 43–45). Originally the crystal was thought to have come from about 11 miles from Glorieta, Santa Fe County, but subsequently it was found that the monazite possibly, but by no means certainly, came from Petaca (Muench, 1938a, p. 2661; 1938b; Northrop, 1944, p. 219; Bates and Burks, 1945, p. 77). As determined from microanalysis by Hecht and Kroupa, the composition of this "Glorieta" monazite is (Lane, 1935, p. 44):

	Percent		Percent
Rare earths	58. 36	CaO	0. 05
ThO_2	10. 67	MgO	. 68
U_3O_8	-----	Pb	. 392
P_2O_5	26. 09	Loss on ignition	1. 72
SiO_2	2. 97		
Al_2O_3	. 67	Total	[1] 102. 55
Fe_2O_3	. 95		

[1] Given as 102.16.

Muench (1938a, p. 2661; 1938b) reported that he was given a piece of monazite by Rufus C. Little who had collected it at the Cribbenville mica mine near Petaca. Meunch made six determinations of the thorium content and three determinations of the uranium content. These determinations are here recalculated to show 8.54, 8.60, 8.61, 8.54, 8.50, and 8.57 percent of ThO_2 and 0.127, 0.118, and 0.127 percent of U_3O_8. The average ThO_2 content is 8.55 percent, and the average U_3O_8 content is 0.124 percent.

The composition of total rare earth plus thorium oxide precipitate from monazite from pegmatite in the Petaca district was described by Murata, Rose, and Carron (1953, p. 294) and is recalculated to sum 69.62 percent—its percentage in the monazite (H. J. Rose, Jr., 1958, written commun.):

	Percent
La_2O_3	12. 94
CeO_2	25. 95
Pr_6O_{11}	2. 95
Nd_2O_3	12. 66
Sm_2O_3	4. 01
Gd_2O_3	1. 90
Y_2O_3	1. 69
ThO_2	7. 52
Total	69. 62

The pegmatite dike at the Harding mine, Taos County, contains monazite as an extremely minor accessory mineral (Jahns, 1953, p. 1090).

The Pidlite mine in the Sangre de Cristo Range in southwestern Mora County is driven in a monazite-bearing lithia pegmatite dike that intrudes Precambrian rocks (Jahns, 1953, p. 1078). The dike is lens shaped and consists of four mineralogical and textural zones, which have a regular concentric arrangement, and three replacement units. Granitoid aggregates of quartz, albite, perthite, and muscovite in variable abundance form relatively thin and continuous outer zones, and very coarse grained aggregates of quartz and perthite make up lenticular or podlike inner zones. The three replacement units have irregular texture and contain abundant sodic albite, lepidolite, and white to pink muscovite. Accessory minerals in the dike are amblygonite, apatite, beryl, betafite, bismuth, bismutite, columbite-tantalite, cyrtolite, fluorite, gahnite, loellingite, magnetite, microlite, monazite, pyrite, spessartite, spodumene, topaz, and tourmaline. Monazite, betafite, and fluorite occur in the wall zone of the pegmatite, and monazite, tourmaline, lepidolite, fluorite, columbite-tantalite, and albite occur in the inner zones of the dike (Jahns, 1953, p. 1093–1094). Monazite is sparse.

The zones in the dike were interpreted by Jahns (1953, p. 1079) to have formed from the fractional crystallization of pegmatite magma in a virtually closed system. Formation of the younger minerals, among which monazite seems to be classed, apparently took place chiefly through direct crystallization and partly through replacement of earlier-formed minerals by residual fluid.

Monazite has been reported from several pegmatite dikes in the Elk Mountain district, Ribera district, and Manzanares Creek area of San Miguel County (Northrop, 1944, p. 219; Crawford, 1956, p. 1212; Anderson, E. C., 1957, p. 13, 29). Anderson also reported that monazite is a common accessory mineral in many masses of granite in San Miguel County. It was said to be particularly common in alteration zones and along the contacts of the granite masses.

Monazite from a vein deposit at Pecos, San Miguel County, was reported to contain 9.86 percent of ThO_2 and 0.34 percent of U_3O_8 (Kauffman and Baber, 1956, p. 6). Monazite from an undescribed locality in San Miguel County was said to contain 10–12 percent of ThO_2 (Crawford, 1956, p. 1212).

Fairly large pieces of monazite have been found in the region southwest of Las Vegas and in the vicinity of Bull Creek in San Miguel County (Northrop, 1944, p. 220). Monazite from the Bull Creek locality was analyzed by O. B. Muench and found to have 10.7 percent of ThO_2 and 0.14 percent of U_3O_8 (Northrop, 1944, p. 220; Muench, 1950, p. 130). The location, size, and composition of the monazite suggest a pegmatitic source.

In the Dalton Creek area on the east side of the Sangre de Cristo Range east of Santa Fe, Santa Fe County, a few pegmatite dikes contain minor accessory monazite (Anderson, E. C., 1957, p. 119). Microscopically small crystals of monazite were reported from the Organ district, Dona Ana County, but the nature of the occurrence was not described (Northrop, 1944, p. 219).

FOSSIL PLACERS

Numerous radioactive fossil placers have been found in Upper Cretaceous sandstones of the San Juan Basin in New Mexico (Chenoweth, 1956; 1957, p. 212; Dow and Batty, 1961, p. 3). Similar fossil titaniferous black sand deposits occur in Arizona, Colorado, Montana, Utah, and Wyoming. The fossil placers are beach concentrates formed at the transition zone from marine to nonmarine beds, and they occur in the Gallup Sandstone, Dalton Sandstone Member of the Crevasse Canyon Formation, Point Lookout Sandstone, and Pictured Cliffs Sandstone. The fossil placers form resistant elongate, lenticular beds associated with clean massive well-sorted littoral marine sandstone which is overlain by lagoonal deposits consisting of coal and shale (Chenoweth, 1957, p. 212). The fossil placers contain ilmenite, hematite, anatase, garnet, zircon, tourmaline, magnetite, rutile, monazite, and several as yet unidentified minerals cemented with carbonate and hematite. Only very sparse monazite has been reported. Many of these placers were discovered because of their unusual radioactivity due to monazite and zircon, and some of the placers have been explored for their titanium-bearing minerals. The possibility of economic development of the placers apparently depends on their titanium content, and monazite might be a byproduct.

The largest group of fossil placers, called the Shiprock group in New Mexico and the southwest Mesa Verde deposits in Colorado, are in the upper part of the Point Lookout Sandstone and lower part of the Menefee Formation exposed between Shiprock, San Juan County, and the State line near Tanner Mesa (Chenoweth, 1957, p. 215–216; Dow and Batty, 1961, p. 40–44). At least 28 separate deposits are known in New Mexico, and the deposits extend northwestward into Colorado (Dow and Batty, 1961, fig. 28). They are poorly and discontinuously exposed, small, and low grade. For the group as a whole, including the extension of the deposits in Colorado, the total tonnage of black sand was estimated as 693,000 short tons having an average grade of as follows (Dow and Batty, 1961, p. 43):

	Percent
TiO_2	2. 8
ZrO_2	. 42
ThO_2	. 03

A semiquantitative spectrographic analysis of black sand from the Shiprock area is given in table 57.

TABLE 57.—*Semiquantitative spectrographic analysis of a bulk sample of a heavy-mineral deposit in the Point Lookout Sandstone exposed in the Shiprock area of New Mexico and Colorado*

[Analyst: Chenoweth (1957, p. 214–215). Theoretical range, in percent: xx, >10; x, 1.0–10.0;. x+, 0.464–1.0; .x, 0.215–0.464; .x–, 0.10–0.215]

Silicon	xx.	Copper	. 0x–
Aluminum	x.	Lanthanum	. x+
Iron	x+.	Niobium	. 0x+
Titanium	xx.	Neodymium	. x
Manganese	. x–	Nickel	. 0x–
Calcium	. x	Lead	. 0x–
Magnesium	. x+	Scandium	. 0x–
Barium	. 0x	Thorium	. x+
Beryllium	. 000x–	Vanadium	. x–
Cerium	. x	Yttrium	. x–
Cobalt	. 0x–	Ytterbium	. 0x–
Chromium	. 0x+	Zirconium	x+.

A low concentration of heavy minerals in a fossil placer in the Pictured Cliffs Sandstone at Barker dome in north-central San Juan County is radioactive and presumably monazite-bearing (Chenoweth, 1957, p. 216–217).

Four monazite-bearing fossil placers were found along the Hogback monocline south of the Shiprock placer area (Chenoweth, 1957, p. 216). Two placers are in the top of the Point Lookout Sandstone, and two are in tongues of the sandstone in the Menefee Formation. The largest placer is at least 525 feet long.

A large fossil placer in Menefee Formation is exposed 2 miles north of Sanostee, San Juan County (Chenoweth, 1957, p. 215; Dow and Batty, 1961, p. 37–40). It is 7,300 feet long, 200–800 feet wide, and 1–14 feet thick. Titanium minerals, magnetite, zircon, and monazite are visibly laminated with quartz and feldspar and cemented by hematite. An analysis of four samples from the placer disclosed an average content of 15.6 percent of TiO_2, 2.6 percent of ZrO_2, and 0.12 percent of $eThO_2$ (Dow and Batty, 1961, p. 40).

Two miles south-southeast of Toadlena, San Juan County, a monazite-bearing titaniferous layer in the Gallup Sandstone is exposed for a strike-length of 500 feet, this layer was thought to be as much as 1,750 feet long, but both ends are covered by alluvium (Chenoweth, 1957, p. 215; Dow and Batty, 1961, p. 37). The layer is 1 foot thick and was reported to contain from 0.4 to 32 percent of TiO_2 and 0.06 percent of $eThO_2$.

A small fossil placer is exposed in the Gallup Sandstone 1 mile north of Defiance and 8 miles west of Gallup, McKinley County (Allen, J. E., 1956; Dow and Batty, 1961, p. 37). It is exposed along both walls of a canyon for a length of 1,500 feet and has a thickness of 1 foot, but its width is unknown. Brookite, rutile, anatase, and leucoxene were said by Allen to be common, but an average of three analyses from the deposit disclosed only 0.5 percent of TiO_2 and 0.02 percent of $eThO_2$ (Dow and Batty, 1961, p. 37). Radioactive zircon was said to be one of the minerals in the placer, but monazite was not specifically mentioned.

A fossil placer in the Point Lookout Sandstone occurs 4.5 miles southeast of Standing Rock Trading Post, McKinley County (Chenoweth, 1957, p. 216). Erosion has divided the original deposit into two parts, both of which are flat-lying beds of titaniferous sandstone. The western part of the placer is 3,500 feet long, 100 feet wide, and 3 feet thick; the eastern part is 2,100 feet long, 350 feet wide, and 8 feet thick (Dow and Batty, 1961, p. 37). An average of 4.3 percent of TiO_2, 0.3 percent of ZrO_2, and 0.06 percent of $eThO_2$ was reported by Dow and Batty from three analyses.

Strong subsurface radioactivity where the top of the Point Lookout Sandstone was intersected at depths of 5,862–5,866 feet, 5,751–5,757 feet, and 6,360–6,365 feet in three gas wells drilled in the San Juan Basin near Gobernador, Rio Arriba County, was attributed by Chenoweth (1957, p. 217) to concentrations of heavy minerals similar to those found locally near the top of exposed parts of the sandstone.

Three fossil placers are exposed in the top of the Point Lookout Sandstone at Stinking Lake, Rio Arriba County (Chenoweth, 1957, p. 216). Two of them seem to be part of the same original deposit. They have an apparent width of 200 feet, length of 2,200 feet, and thickness of 5 feet. The third deposit is exposed for a length of about 1,000 feet and is about 5 feet thick.

Three small flat-lying erosional remnants of a fossil placer in the Pictured Cliffs Sandstone near Star Lake Trading Post, McKinley County, are about 30 feet in diameter and 5 feet thick (Chenoweth, 1957, p. 216; Dow and Batty, 1961, p. 34–35). They seem to have been originally much larger. Monazite is a sparse accessory mineral in the heavy-mineral suite at the Star Lake deposit.

A fossil placer having an exposed length of 300 feet and thickness of 2–4 feet occurs in the top of the Point Lookout Sandstone on the B. P. Hovey Ranch, Sandoval County (Chenoweth, 1957, p. 216).

Two small poorly exposed fossil placers occur in the Dalton Sandstone Member of the Crevasse Canyon Formation on San Miguel Creek near the center of the Miguel Creek dome, McKinley County (Chenoweth, 1957, p. 215; Dow and Batty, 1961, p. 35–37). A composite sample from three excavations was analyzed by Dow and Batty and found to contain 4.0 percent of TiO_2, 0.4 percent of ZrO_2, and 0.03 percent of $eThO_2$.

Two small fossil placers have been reported from an area near the Herrera Ranch west of Bernalillo, Sandoval County (Chenoweth, 1957, p. 215–216). One is a relict preserved in an area 50 feet wide and 200 feet long in the top of the Gallup Sandstone. It is only 12–14 inches thick, but originally it was apparently much thicker and as much as 3 miles long. The other fossil placer is of undescribed size and probably occurs in the Point Lookout Sandstone.

FLUVIAL AND OTHER SURFICIAL DEPOSITS

Small amounts of monazite-bearing stream sand and other surficial deposits have been reported from several localities in New Mexico, the earliest reports being those of Day and Richards (1906b, p. 1204–1205) who noted a trace of monazite in black sand from

Los Cerrillos, Santa Fe County, and Shandon, Sierra County. At Los Cerrillos the raw sand contains 8 pounds of heavy minerals per short ton, and at Shandon the raw sand contains 40 pounds of heavy minerals per cubic yard (about 28 pounds per short ton). The composition of these concentrates is as follows (Day and Richards, 1906b, p. 1204–1205):

	Pounds per short ton	
	Los Cerrillos	*Shandon*
Magnetite	1, 088	832
Ilmenite	325	400
Hematite	350	500
Monazite	Trace	5
Zircon	Trace	-------
Quartz	------	263
Other minerals	237	-------
Gold and platinum	Trace	-------
Total	2, 000	2, 000

The very large amount of hematite is a noteworthy feature of these concentrates.

Monazite-bearing black sands have also been reported in the area between Tuer and Arroyo, Santa Fe County, and in Pittsburg district, Sierra County (Northrop, 1944, p. 220). At both places the sands contain only a trace of monazite. Sand from the Chama River in Rio Arriba County was stated to contain monazite (Jones, F. A., 1915, p. 76; Northrop, 1944, p. 219). The Lost Creek area near San Geronimo, San Miguel County, was reported (Uranium Mag., 1955) to contain 4 million short tons of monazite-bearing sand, but an adequate description of the occurrence was not given.

Each of eight samples of heavy minerals from sediments collected by Rittenhouse (1943, p. 1734–1735) at evenly spaced intervals across the Rio Grande at Bosque, Valencia County, contained monazite. The concentrates consisted of dominant ilmenite, pyroxene, amphibole, epidote, and mica and sparse monazite, tourmaline, zircon, apatite, garnet, sphene, barite, staurolite, kyanite, zoisite, sillimanite, andalusite, rutile, and topaz. Monazite was also reported by Rittenhouse (1944, p. 166–168) to be sparse, or possibly present, mineral in concentrates from sands of the Rio Grand and its tributaries from San Marcial, Socorro County, upstream to Embuda, Rio Arriba County, and the Chama River at Abiquiu, Rio Arriba County. Particular localities were not cited for monazite.

NEW YORK

CRYSTALLINE ROCKS

A very little monazite(?) has been identified in crystalline rocks in the St. Lawrence County magnetite district in the northwestern Adirondack Mountains (B. F. Leonard, written comun., 1959). Monazite possibly occurs as a disseminated accessory mineral in magnetite-rich granite gneiss, in skarn, and in garnetiferous quartz rock associated with skarn.

Small amounts of monazite were reported by McKeown and Klemic (1956, p. 11–14) to occur in magnetite ore of the Old Bed at Mineville, Essex County. The magnetite ore at Mineville occurs in a layered sequence of complexly folded and highly metamorphosed igneous and sedimentary rocks of Precambrian age. Possibly the rocks are mixtures of Grenville sedimentary and igneous intrusives. The lowest unit in the sequence that includes the Old Bed is gabbro. Overlying the gabbro is the Old Bed magnetite ore, and in succession above the ore granite gneiss grades through diorite into gabbro that is overlain by magnetite ore of the Harmony Bed. The Old Bed magnetite ore contains a gangue of fluorapatite and feldspar, pyroxene, and quartz. Monazite, bastnaesite, and hematite commonly occur as inclusions in the fluorapatite, and they also form thin rinds on some of the apatite grains. Magnetite formed later than these minerals, thus, it commonly encloses fluorapatite both with and without rinds. The total amount of monazite is not great.

Layers of quartz, quartz-sulfide rock, and schistose gneiss in the Carmel Gneiss west of Carmel, Putnam County, contain minor amounts of very radioactive monazite (McKeown, 1951, p. 34). In the Bear Mountain area, Rockland County, garnetiferous quartz-feldspar-biotite gneiss was thought by McKeown (1951, p. 13–14) to be monazite bearing.

Transparent simple crystals of monazite occur in brown quartz adjoining magnetite-rich layers in coarse-grained sillimanite gneiss at Yorktown Heights, Westchester County (Silliman, 1844, p. 208; Beck, 1850, p. 150; Shepard, C. U., 1852, p. 109; Manchester, 1931, p. 98; Palache and others, 1951, p 695). The locality was described by Bodelson (1948, p. 908–909) as being an outcrop of Manhattan Schist at the Rockledge Farm on Hanover Avenue. As exposed, the Manhattan Schist consists of garnetiferous sillimanite-biotite schist, some gneiss, and rare, small pegmatite dikes. Inclusions of magnetite occur in the sillimanite, and inclusions of monazite occur in the magnetite. Locally the magnetite forms small masses which are penetrated by crystals of sillimanite and contain inclusions of monazite.

Good crystals of monazite are associated with fine-grained sillimanite in amphibole-bearing sillimanite-mica schist at Croton Lake, Westchester County (Whitlock, 1903, p. 100–101; Manchester, 1931, p. 69).

Monazite was reported (Mineral Collector, 1908, p. 90) from several localities in and near the Washington Heights area of upper Manhattan Island, New York City, New York County. Apparently the earliest of these reports were accounts by Hidden (1888a; 1888b, p. 381) and Chamberlin (1888, p. 220) of monazite found by William Niven in the vicinity of 155th Street and Broadway (11th Avenue). The monazite-bearing samples from this locality were reported by Hidden (1888b, p. 381) as also containing tourmaline, apatite, muscovite, orthoclase, zircon, chrysoberyl, xenotime, cordierite, and pinite; but the geologic setting of the material was not described. From the mineral association it would seem that the samples came from pegmatite. Possibly the source was identical with the monazite-bearing pegmatite vein referred by Whitlock (1903, p. 48–49) and Gratacap (1909, p. 139) to a locality at 155th Street and Amsterdam Avenue (10th Avenue), one block east of Niven's reported sample site. Zircon, xenotime, and garnet are associated with the monazite in the pegmatite at Amsterdam Avenue. Monazite, xenotime, and tourmaline, possibly accompanied by zircon, dumortierite, muscovite, and autunite, were observed in pegmatite in Manhattan Schist exposed at 171st Street and St. Nicholas Avenue (11th Avenue) in Washington Heights (Whitlock, 1903, p. 50–51; Fettke, 1914, p. 234–235). What is probably the same occurrence of monazite, although referred to 171st Street and Fort Washington Avenue (Hovey, 1895; Baskerville, 1903, p. 466), is a vein of coarse-grained pegmatite in mica schist. The vein is composed of granular gray quartz, orthoclase, and muscovite, and contains several small euhedral translucent crystals of clove-brown monazite associated with xenotime. Monazite closely associated with xenotime and ilmenite was found in oligoclase selvages of a coarse-grained granitic vein in schist and gneiss at 185th Street and the Harlem River (Niven, 1895).

CONSOLIDATED SEDIMENTARY ROCKS

Detrital heavy minerals in the Tully Limestone of Devonian age exposed between Tully, Onondaga County, and Canandaigua Lake, Ontario County, were examined by Trainer (1932, p. 18–29). He found that tourmaline and zircon are the most common heavy minerals in the limestone. They are accompanied by sparse leucoxene and rutile and many exceedingly sparse minerals including augite, plagioclase, monazite, apatite, sillimanite, hornblende, garnet, staurolite, hypersthene, ilmenite, magnetite, hematite, and sphene. The monazite occurs as round honey-yellow grains. Their probable source is the metamorphic and igneous rocks of the Canadian Shield and the Adirondack Mountains area, but Trainer emphasized that too little is known about the distribution of the heavy accessory minerals in the plutonic rocks to permit secure identification of the source of the detrital grains by mineralogy alone. Other sedimentary factors, however, including variation in the total abundance of the heavy minerals, thickness of the Tully Limestone, and attitude of the ripple marks tend to indicate that the Adirondack Mountains area was the region from which the heavy minerals derived. If this conclusion is correct, then monazite is evidently a more common accessory mineral in the plutonic rocks of the Adirondack Mountains than the literature indicates.

BLACK SAND

Auriferous black sand of unreported source from Lewis County, N.Y. was described by Day and Richards, (1906b, p. 1204–1205) as containing a trace of monazite per short ton:

	Pounds per short ton
Magnetite	1, 744
Ilmenite	24
Garnet	24
Hematite	56
Zircon	24
Quartz	24
Other minerals	96
Total	1, 992

BEACH SAND

Three samples of beach sand from Long Beach, Nassau County, and West Hampton and Amagansett, Suffolk County, on the south shore of Long Island, were observed by Martens (1935, p. 1594–1595) to contain a very small amount of monazite. An average of the analyses of the heavy-mineral fraction from the three samples showed the following mineralogical composition:

	Frequency percent		*Frequency percent*
Black opaque minerals	21. 0	Tourmaline	3. 2
Zircon	1. 1	Garnet	26. 0
Rutile	. 7	Leucoxene	6. 5
Epidote	3. 1	Monazite	. 4
Staurolite	15. 0	Sphene	. 2
Sillimanite	2. 4	Hypersthene	. 7
Kyanite	2. 5	Andalusite	. 7
Hornblende	17. 0		

The beach sands are derived from glacial outwash and morainic deposits which were little weathered at the source; hence, the unstable minerals are fairly abundant.

NORTH CAROLINA

Monazite was first reported to occur in North Carolina in 1849 when C. U. Shepard (1849, p. 275; 1852, p. 109) briefly mentioned its association with brookite in the gold placers of Rutherford County. The casual way the observation was made seemingly indicates that the occurrence was already known, even well known, and Shepard's remark might also be interpreted to mean that a previous and more formal account of the discovery of monazite in North Carolina had been published, but such is not the fact. No independent evidence for either assumption has been found. For 30 years thereafter scant attention was paid to the occurrences of monazite in North Carolina because there was no commercial demand for the mineral. A little notice was given it in 1862 and again in 1871 by F. A. Genth. About 1862 Genth found a crystal of monazite in auriferous concentrates from Todds Branch in Mecklenburg County (Genth, 1862, p. 204), and in 1871 he wrote that monazite had been reported from gold placers in Rutherford, Burke, and McDowell Counties, but he had not as yet seen it elsewhere than Burke and Mecklenburg Counties (Genth, 1871, p. 81). Industrial interest in the monazite began in 1879 when W. E. Hidden was dispatched by Thomas A. Edison to North Carolina to explore for the ores of rare metals to be used in experiments with illuminating apparatus (Hafer, 1941, p. 291). By 1880, Hidden had discovered that monazite was a common detrital mineral in gold placers in parts of Alexander, Burke, McDowell, Rutherford, and Polk Counties and that it occurred as a rare accessory mineral in mica pegmatites in Mitchell and Yancey Counties (Genth and Kerr, 1881, p. 72–73). On November 20, 1880, Hidden wrote that he had sent to Mr. Edison more than 50 pounds of concentrate from the Captain J. C. Mills gold mine in the Brindletown placer district, Burke County, and that the concentrate contained 60 percent of monazite (Genth and Kerr, 1881, p. 84). This was the first monazite produced in North Carolina and in the United States.

During the period 1881 through 1892, interest in monazite in North Carolina continued to grow. This growth is evidenced by the publication of descriptions of concentrates from Burke County (Mallet, 1882, p. 205; Am. Naturalist, 1883, p. 313; Dana, E. S., 1882, p. 247–248) and analyses of monazite and monazite sand from the Brindletown district in Burke County (Penfield, 1882, p. 251; Dana, 1884, p. 542; Eng. and Mining Jour., 1888, p. 2), by a display of monazite from Alexander County at the New Orleans World's Industrial and Cotton Centennial Exposition of 1884–85 (Hidden, 1885, p. 183), by the discussion of the occurrence of monazite in Alexander County (Rath, 1886, p. 149–150; Hidden, 1888b, p. 381) and Mitchell County (Phillips, 1888, p. 398), and by the discovery of monazite in pegmatites at Zirconia, Henderson County, and at Mars Hill in Madison County (Hidden, 1888b, p. 381; Genth, 1891, p. 78). From 1881 through 1885, monazite apparently was not mined in North Carolina. In 1886, mining began in the Brindletown gold placer district, and in 1887, the district furnished 12 short tons of monazite concentrate. From 1888 through 1892 a combined output of a few short tons of monazite was achieved annually at Brindletown and several neighboring areas from small hand-mining operations, but the sources and quantities were not recorded (Nitze, 1895a, p. 689; Pratt, 1902, p. 61; 1903, p. 183; Schaller, 1922, p. 4, 11). Records begun in 1893 show a sustained production of monazite in North Carolina through 1910 with a small and intermittent output through 1917 (see table 30). The abrupt fall in production during 1896 and 1897 reflects the introduction in 1895 of large quantities of Brazilian monazite into world commerce (Dennis, 1898, p. 487; Sci. Am. 1899; Pratt, 1902, p. 61; Mining and Sci. Press, 1902; Eng. and Mining Jour., 1906c, p. 713), and the demise of the industry was brought about by the start of monazite mining in India (Meisner, 1929, p. 234; Houk, 1946, p. 11–12; Roots, 1946, p. 50).

Despite a report that monazite was practically exhausted in the North Carolina deposits by 1897 (Nitze, 1897, p. 131–132), the reserves were conservatively estimated in 1915 as 15,000–20,000 short tons of monazite (Kithil, 1915, p. 19), and when mining ceased there was said to be an abundance of monazite in the streams (Schaler, 1919, p. 156). Abandonment of the placers was caused by a decline in the price of monazite, not by a lack of the mineral. The period of greatest activity in the commercial exploitation of monazite in North Carolina was also a time of increase in the literature on the deposits, and a contemporary bibliography lists 44 papers on monazite in North Carolina by 1909 (Laney and Wood, 1909, p. 403).

Several times between 1917 and 1960 renewed interest in domestic sources for monazite has led to mining activity in North Carolina. Between 1929 and 1936 some prospecting and development were done in Burke and Cleveland Counties, but even in the depression years monazite could not be mined in competition with the imported mineral (Bryson, 1937, p. 132). A preliminary field investigation of 23 monazite deposits in Rutherford, Burke, and Cleveland Counties, N. C., and Cherokee County, S. C., was made early in World War II by the Regional Products Research Division of the Tennessee Valley Authority. Results of the investigation showed that these domestic sources could serve as a substitute for Brazilian and Indian monazite under conditions of critical short supply (McDaniel, 1943; Lefforge and others, 1944). Between 1945 and 1954 considerable work was done on the occurrence of monazite in the Southeastern States, including North Carolina, by the U.S. Geological Survey and U.S Bureau of Mines, in part sponsored by the U.S. Atomic Energy Commission (Broadhurst, 1955, p. 79-80). Field parties of the U.S. Geological Survey delineated the regional distribution of monazite in crystalline rocks (Mertie, 1953, pl. 1), showed the local distribution of monazite in schists and gneisses (Overstreet, Yates, and Griffitts, 1963a), appraised fluvial placers in the western Piedmont province (Overstreet, Theobald, and Whitlow, 1959), and made a reconnaissance of the occurrence of monazite in sedimentary rocks of the Coastal Plain province (Dryden, 1958, p. 398–401). Activity by the U.S. Bureau of Mines consisted of drilling fluvial placers in the western Piedmont province at locations recommended by the U.S. Geological Survey (Griffith and Overstreet, 1953a, b, c; Hansen and White, 1954; Hansen and Cuppels, 1954). The resources in monazite in tributaries to the Broad River and southern tributaries to the Catawba River in North Carolina comprising placers in Cleveland, Rutherford, Polk, McDowell, Burke, Catawba, and Lincoln Counties were estimated to be at least 490,000 short tons (Overstreet, Theobald, and Whitlow, 1959, p. 713). During 1951 through 1953 several private companies explored monazite placers in the western Piedmont province of North Carolina, and one organization opened a placer and constructed a separatory plant on the upper part of the First Broad River between Carson Mountain and Richland Mountain in Rutherford County. The venture operated for 1 or 2 years, and produced some monazite during 1953 (Councill, 1955, p. 6). There was no other recorded output of monazite in North Carolina between 1917 and 1960. In the late 1950's mineral collectors showed interest in the placers (Allen, Fred, 1958; Allen, Mrs. Fred, 1958, p. 328; Yedlin, 1958, p. 419; Zodac, 1958).

As early as 1893, occurrences of placer monazite were known in Burke, Cleveland, Rutherford, Catawba, Gaston, Lincoln, McDowell, Polk, and Mecklenburg Counties, and by 1908 the known distribution of placer monazite had been extended to Alexander, Caldwell, Clay, Iredell and Wilkes Counties in North Carolina (Mezger, 1895, p. 822; 1896; Nitze, 1897, p. 129; Pratt, 1908, p. 61; Sterrett, 1908b, p. 274; 1908c, p. 72–73; Pratt and Sterrett, 1908a, p. 315; 1908b, p. 63; Pratt and Berry, 1911, p. 72–81). The first three of these counties were probably the main sources of monazite during the 1890's, but records prior to 1900 give scant information on the relative positions of the counties as producers. Cleveland County seems to have been a leading source for monazite during 1898 and 1899 (Sci. Am., 1899). In 1902 and 1905, monazite was shipped from Burke, Cleveland, Lincoln, McDowell, and Rutherford Counties (Pratt, 1904a, p. 15; 1904b, p. 1164; 1904c, p. 35; 1907a, p. 41), and in 1915 through 1917, it came mostly from Burke, Cleveland, Iredell, Lincoln, and Rutherford Counties (Pratt and Berry, 1919, p. 104–105), but their rank as producers is not known. Burke, Cleveland, and Rutherford Counties were the main sources of monazite between 1900 and 1907 (table 58).

The source of the monazite was Recent alluvium and colluvium in the valleys of small streams, except at two places in Cleveland County where efforts were made beginning in 1900 to mine monazite from weathered crystalline rocks (Pratt, 1901, p. 31; D'Allier, 1906, p. 30; Kithil, 1915, p. 19; Levy, S. I., 1924b, p. 80.) The only deposits that were successfully worked for monazite were the stream placers and associated colluvium on the valley sides (Mining Jour., 1894; Graton, 1906, p. 117; Böhm, 1906; Schaller, 1919, p. 156; Hess, 1937b, p. 524). Monazite was mined by hand methods in a small way, commonly as part-time or off-season work by the landowners themselves. The stream beds were narrow and shallow. At most of the mines the thickness of the alluvium, including overburden, was only 1–8 feet, and the valley floors were seldom more than 100 or 200 feet wide and 300 feet to a mile in length (Sterrett, 1908b, p. 280; Pratt and Sterrett, 1908a, fig. 4; 1909; Santmyers, 1930, p. 10). In some valleys the placers were mined for a distance of a mile or two, and along many small streams the creek beds were mined several times a year because they were replenished following heavy rains by runoff which brought in monazite from cultivated fields on the adjacent hillsides (Graton, 1906, p. 117;

TABLE 58.—*Relative rank in production of monazite-producing counties in North Carolina by years of available data, 1900–1907*

[Ranked annually in numerical order of decreasing production, leading county numbered 1]

	Alexander	Burke	Catawba	Cleveland	Iredell	Lincoln	McDowell	Polk	Rutherford	Reference (Pratt)	
										Date	Page
1900	--------	2	--------	1	--------	--------	--------	--------	3	1901	31
1901	--------	1	--------	2	--------	--------	3	--------	4	1902	61
1903	--------	3	--------	4	--------	5	2	--------	1	1904b	35
1904	--------	2	--------	1	--------	5	3	--------	4	1905	46
1906	--------	3	7	1	8	5	4	6	2	1907b	122
1907	5	3	6	1	4	--------	--------	--------	2	1908	66

Sterrett, 1908b, p. 280; Pratt, 1916, p. 49). In Cleveland County, monazite was recovered from weathered biotite gneiss rich in pegmatite exposed at the workings of the British Monazite Co. on Hickory Creek about 3 miles northeast of Shelby and at the F. K. McClurd mine about 0.75 mile northeast of Carpenter Knob (Sterrett, 1908b, p. 281). At both localities the monazite content of the gneiss proved to be very variable, ranging from 0.03 to 1.1 percent of the weight of the weathered rock. The ventures failed because sufficient high-grade ore could not be obtained.

Monazite was virtually the only product from the North Carolina placers. A small amount of gold was recovered from some placers in Cleveland County (Pratt and Sterrett, 1909; Pratt, 1914, p. 19), and similar small output doubtless was achieved also in parts of Burke, McDowell, and Rutherford Counties. There seems to have been some interest in the marketing of accessory garnet for use as an abrasive, and some was shipped, but it was either rejected or sold at low prices because it was unsuited in size and shape to the demands of the trade (Pratt, 1908, p. 66; Keith and Sterrett, 1931, p. 13).

The monazite in the form of small batches of rough concentrate was generally carted from the mines to local cleaning plants where the concentrate was sold by the miners at prices governed by the monazite content. At the cleaning plants the rough concentrate, which consisted of a complex group of minerals (Boudouard, 1898, p. 11) in which ilmenite, garnet, zircon, sillimanite, tourmaline, and rutile were most common but which locally contained upwards of 100 varieties of minerals (Eng. and Mining Jour., 1896) were processed into shipping grade monazite sand. This product has been variously described as containing 66 percent of monazite (Barker, 1903, p. 165), 65–70 percent of monazite (Chemische Zeitschr., 1906), 80 percent or more of monazite (Franklin Inst. Jour., 1908, p. 318), and 92–95 percent of monazite (Ladoo, 1925, p. 396).

The thorium oxide content of the rough concentrate from the mines was very variable owing to differences in the amount of monazite in individual batches of concentrate and to variations in the abundance of thorium oxide in the monazite itself. Several old analyses of these concentrates were published. Some have been called analyses of monazite, but they are analyses of mixtures of monazite and other minerals. Nine samples of monazite sand containing as much as 67 percent of monazite and from unspecified localities were reported by Nitze (1895b, p. 21) to have 0.125, 0.175, 0.225, 0.26, 0.29, 0.40, 1.27, 3.40, and 5.19 percent of ThO_2. Concentrates from known localities were reported by Pratt (1902, p. 60; 1903, p. 182) to contain from 1.27 to 7.28 percent of ThO_2:

	ThO_2 (*Percent*)
Burke County:	
White Bank gold mine	2. 15
Hall Creek	2. 25
Linebacher place, Silver Creek	6. 54
Locality unknown	7. 28
McDowell County:	
Long Branch	1. 27
Alexander Branch	6. 30
MacLewrath Branch	2. 48
Cleveland County:	
Proctor farm, Belwood	5. 87
Wade McCurd farm, Carpenter Knob	6. 26
Davis mine, Mooresboro	3. 98
Concentrate from weathered rock	7. 01
Rutherford County:	
Near Henrietta	1. 93

Complete analyses of low-thorium oxide Carolina monazite sand show the following composition:

[Analysts: *A*, Boudouard (1898, p. 12); *B*, Chernik (1908, p. 250)]

	Percent	
	A	*B*
CeO_2	12. 50	[1] 45. 40
$Di_2O_3 + La_2O_3$	8. 07	6. 56
Y_2O_3 (group)	. 48	2. 07
ThO_2	2. 42	1. 22
P_2O_5	39. 48	23. 43
SiO_2	9. 56	1. 60
$Al_2O_3 + Fe_2O_3$	9. 85	[2] 11. 69
TiO_2	6. 63	-------
ZrO_2	5. 75	3. 25
$Nb_2O_5 + Ta_2O_5$	4. 12	-------
MgO	3. 74	-------
H_2O	. 20	-------
Other oxides	(3)	(4)
Insoluble residue	1. 55	-------
Total	100. 23	99. 34

[1] Ce_2O_3.
[2] Al_2O_3, 2.49; Fe_2O_3, 5.58; FeO, 3.62.
[3] CaO, trace; Be_2O_3, trace.
[4] MnO, trace.

After upgrading at the cleaning plants, the shipping product was said to have had variously 4 percent of ThO_2 (Barker, 1903, p. 165), 5 percent of ThO_2 and 0.43 percent of U_3O_8 (Boltwood, 1905, p. 607–608; Pratt, 1905, p. 41), 3–9 percent of ThO_2 (Fleck, 1909, p. 205), 5–6 percent of ThO_2, and 61–62 percent of RE_2O_3 (Kremers, 1958, p. 2). As in the reports on the tenors of the crude concentrates, there is an increase in the amount of thorium oxide in the product as the industry improved its methods of preparing concentrates, and the product shipped in the last years of mining was more nearly pure monazite and thus contained more thorium oxide than the product sold in the early years. A concentrate consisting of nearly pure monazite milled in 1943 was reported to contain 7 percent of ThO_2 (McDaniel, 1943).

An analysis of helium-bearing monazite from an unspecified locality in North Carolina was reported by Thorpe (1895) to show 18.01 percent of ThO_2 and 1.62 percent of SnO_2, but the amount of helium was not given:

	Percent
Ce_2O_3	25.98
La_2O_3	23.62
ThO_2	18.01
P_2O_5	28.43
SnO_2	1.62
CaO	.91
MnO	1.33
Total	99.90

Among the many analyses of monazite from Carolina that have subsequently been made, none discloses as much thorium, and among analyses of monazites from the United States only an old one of material from pegmatite at Amelia Court House, Va., and a recent one of monazite from pegmatite at Yucca Valley, San Bernardino County, Calif., have more than 18 percent of ThO_2. The large quantity of tin is also most unusual for North Carolina monazite.

Other early descriptions of monazite from North Carolina mentioned that it contains helium and is radioactive (Barker, 1903, p. 164–165; Strutt, 1904, p. 193; Boltwood, 1905, p. 611), discussed the presence of thorium and rare earths (Hutchinson, Arthur, 1909, p. 214–215; James, 1913, p. 238), and showed that monazite displays neither fluorescence nor phosphorescence if subjected to ultraviolet radiation (Baskerville, 1903, p. 466).[2]

Detailed analyses of purified samples of monazite from North Carolina were made as early as 1882 (Penfield, 1882, p. 252), and others were recorded intermittently through the life of the monazite industry. A spate of analyses was introduced during the late 1930's as a result of an interest in using radioactive minerals to study geologic time. In the 1940's and early 1950's scores of analyses were made when there was a revival in demand for monazite as a source for thorium. These analyses are given farther along in the text where individual localities are discussed.

HYPOTHESES OF ORIGIN

The origin of monazite in the crystalline rocks of North Carolina received scant attention during the life of the industry. Monazite in granitic rocks and pegmatite was interpreted to have formed as a primary accessory mineral, whereas that in schists and gneisses was attributed to impregnation from the granitic intrusives (Mezger, 1895, p. 823; Nitze, 1897, p. 128; Pratt, 1903, p. 180–181; Graton, 1906, p. 117; Pratt, 1907b, p. 113; Sterrett, 1908b, p. 284–285; Pratt and Sterrett, 1909). The absence of monazite from parts of the State most widely underlain by granitic rocks was not at that time recognized, probably because suitable geologic maps were lacking; hence, the apparent conflict between the postulated origin and the spatial distribution of the monazite was not perceived.

The beltlike extent of the monazite-bearing area in the western Piedmont of North Carolina was recognized in the early 1900's and the opinion was expressed that the trend would persist for many miles toward the northeast and southwest beyond the then-known limits near Wilkesboro, N.C., and Anderson, S.C. (Pratt, 1907b, p. 109; 1916, pl. 1). After the close of the industry in 1917, further exploration for monazite was halted until 1945 when Mertie began to study the distribution of monazite in the crystalline rocks of the Southeastern States. Mertie (1953, pl. 1) was able to show that the early predictions about the probable extent of the monazite belt in the western Piedmont were correct and that the belt extended at least to Fredericksburg, Va., and to the Coosa River, Ala. For all this additional extent, only Surry County, N.C., was added to the group of known monazite-bearing counties in the western Piedmont of North Carolina. In the eastern part of the State, however, a previously unknown linear zone of monazite-bearing crystalline rocks was discovered by Mertie (1953, pl. 1) in Warren, Franklin, and Wake Counties. This belt converges northward to the western Piedmont belt in Virginia. Later, Mertie found another linear zone of monazite-bearing crystalline rocks in the Blue Ridge in the western part of the State (Mertie, 1957). The Blue Ridge belt extends into Virginia and Georgia.

The localized occurrence of monazite in belts was seen by Mertie to be a fundamental factor in the origin of monazite in the Southeastern States. In his explanation for the distribution of monazite, of which only a preliminary statement and slight revision (Mertie, 1953, p. 29–30; 1958, p. 4) were available as of 1962 when this review was written, the belts were interpreted to be the sites of Precambrian sedimentation, not necessarily active at the same time, in which concentrations of detrital monazite were formed as old Precambrian monazite-bearing source rocks were eroded. These sedimentary rocks and the contained monazite placers were later reconstituted by heat and pressure into metamorphic rocks. Some of the sedimentary material, and possibly some

[2] Murata and Bastron (1956) showed that monazite and other transparent cerium-earth minerals strongly absorb the violet, blue, and yellow radiation from an unfiltered medium-pressure mercury-vapor lamp and transmit the green radiation, with the result that the mineral assumes the emerald-green color of the unabsorbed radiation.

of the monazite-bearing source rocks, were locally melted to form monazite-bearing intrusive rocks. The three belts include various kinds of crystalline rocks of which many do not contain monazite. The belts are not geologic formations, and they cut across the strike of known stratigraphic units. They are inferred to be the traces of the monazite-enriched sedimentary basins, and the grains of monazite are inferred to be mainly relict detrital particles that have withstood the metamorphism (Mertie, 1953, p. 29–30).

Accessory ilmenite and magnetite were thought by Mertie (1953, p. 30) to have had somewhat equal abundance in most of the early Precambrian source rocks from which the monazite-bearing sediments were derived. During the sedimentary cycle or cycles through which the detrital monazite passed, a partition is thought to have taken place in the relative abundance of accompanying detrital ilmenite and magnetite because ilmenite is much more abundant than magnetite in the monazite-bearing metasedimentary rocks. Presumably magnetite was eliminated from the sedimentary rocks prior to metamorphism by the well-known tendency of magnetite to oxidize and be destroyed during weathering and transport. Under the same conditions, ilmenite was more stable than magnetite; therefore, loss of magnetite was accompanied by relative increase in ilmenite. After long-continued weathering ilmenite also tended to be removed from the natural heavy-mineral suite of the sedimentary rock. This partition during the sedimentary cycle resulted in the development of three distinct nongradational types of heavy-mineral suites. These are an ilmenite-rich type, a type lean in both ilmenite and magnetite, and a scarce type rich in magnetite. The common ilmenite-rich type of monazite concentrate is interpreted to be a typical placer assemblage in which relict stable detrital ilmenite accompanies relict detrital monazite in the metasedimentary rocks. Monazite concentrates of the type lean in ilmenite and magnetite are interpreted to have come from sedimentary rocks which had undergone long periods of weathering during one or more sedimentary cycles. The scarce, magnetite-rich type of monazite concentrate was ascribed to rocks formed in local remobilized zones in the original Precambrian monazite-bearing source rocks. The dominant concept of this interpretation is the persistence of original detrital heavy minerals from the sedimentary cycle through the metamorphic cycle and the control their original basins of sedimentary deposition exerts over the present geographic distribution of the monazite-bearing rocks.

The location as shown by Mertie of the belt of monazite-bearing crystalline rocks in the western Piedmont was used by the writer and his associates between 1951 and 1954 as a guide in a program of sampling fluvial placers. About 4,200 concentrates were panned from stream sediments, and the concentrates were examined mineralogically in the laboratory of the U.S. Geological Survey by a staff under Jerome Stone. The results of this work (Overstreet, Theobald, and others, 1956; Overstreet, Theobald, and Whitlow, 1959, p. 709–710) showed that the actual boundaries of the Carolina segment of the belt were virtually the same as the boundaries drawn by Mertie from reconnaissance. Other results in agreement with Mertie's observations were that the belts cut across stratigraphic units, that they were formed at different times, and that the abundance of monazite increases in areas where ilmenite dominates over magnetite. In this work, however, and in earlier and later studies, the writer and his coworkers discovered several facts and noted previously uncorrelated observations that bore on the origin of monazite and led to an interpretation fundamentally different from the one given by Mertie. This interpretation proposes that the belts of monazite-bearing metasedimentary rocks define zones of regional metamorphic climax in which much of the monazite originated as a metamorphic mineral derived from components available in normal shale and sandstone and that detrital concentration of monazite in the original sediments is not a precondition for the localization of the belts. The belts were thought to have formed during three orogenic events in the southern Appalachians, and each belt is associated with a different culmination This interpretation is thought to provide a basis for predicting the occurrences and composition of monazite in crystalline rocks elsewhere in the world. The general aspects of the interpretation have been presented previously in this and other reports (Overstreet, 1960), and the details are given elsewhere; however, a summary as it applies to the Southeastern States is an appropriate introduction to a discussion of monazite in North Carolina.

A regionally concordant trend and direct relation were found in the monazite belt in the western Piedmont between the abundance of monazite in present sediments of small streams and the abundance of associated sillimanite, almandine, ilmenite, and rutile. A regionally concordant trend and inverse relation were found between the abundance of monazite and that of staurolite, kyanite, epidote, and magnetite. The abundance of monazite increases in these fluvial sediments as the abundance of sillimanite, almandine, ilmenite, and rutile increases and as the abundance of staurolite, kyanite, epidote, and magnetite decreases. Inasmuch as these small streams drain saprolite and residual soil, the striking antipathetic relations between the two groups of minerals were interpreted to reflect conditions of regional metamorphism in the underlying crystalline rocks (Overstreet and Griffitts, 1955, p. 555; Overstreet, Cuppels, and White, 1956, p. 595–596; Overstreet, 1962, p. 158–162). Sillimanite, almandine, ilmenite, and rutile are associated in metamorphic rocks of the sillimanite-almandine subfacies of the amphibolite facies (Turner, F. J., 1948, p. 81–87). Staurolite, kyanite, epidote, and magnetite occur in rocks of lower metamorphic facies. The regionally concordant trend and direct relation between the abundance of monazite and the minerals formed by high-grade regional metamorphism were interpreted by the writer and his associates to indicate that the major geologic control of the distribution of monazite was increasing grade of regional metamorphism.

Details of the variation in the abundance of monazite related to the kind of crystalline rocks in the monazite belt in the western Piedmont were examined by R. G. Yates and others in the Shelby quadrangle, Cleveland and Rutherford Counties. Geologic mapping showed that the quadrangle was underlain by thick sequences of sandstone, graywacke, and shale with sparse interbedded felsic volcanic rocks, which were isofacially metamorphosed at the upper amphibolite facies (Overstreet, Yates, and Griffitts, 1963b). The metamorphosed stratified rocks consist principally of biotite schist, sillimanite schist, and biotite gneiss which respectively underlie 62 percent, 30 percent, and 1 percent of the area of the quadrangle. These rocks were intruded by synkinematic quartz monzonite, which underlies 7 percent of the area of the quadrangle. The distribution and abundance of monazite in the crystalline rocks were determined by examining panned concentrates from 1,241 samples of saprolite. Monazite was found to be most frequently present and most abundant in the quartz monzonite, pegmatite, and sillimanite schist. It was found to be least commonly present and least abundant in the biotite schist. Contours drawn on a map of the Shelby quadrangle to show the abundance of monazite in the isofacial metasedimentary rocks disclosed a consistent pattern of low percentages that occupy the main areas underlain by biotite schist and high percentages that occupy the principal zones underlain by sillimanite schist (Overstreet, Yates, and Griffitts, 1963a, pl. 1).

Other evidence, although indirect, also indicates that the sillimanite schist is the preferred host for monazite among the metasedimentary rocks. An airborne radioactivity survey of the northern part of the Shelby quadrangle disclosed that radioactivity highs resulting from monazite in residual soils form over sillimanite schist, and lows form over biotite schist (Overstreet, Meuschke, and Moxham, 1962). Several eU analyses of bulk samples of rocks from the Shelby area show that sillimanite schist is about three times as radioactive as biotite schist (W. R. Griffitts, written commun., 1954):

[Analyst: J. Patton, 1953]	*Number of samples*	eU *(ppm)*
Sillimanite schist	1	30
Biotite schist	2	10
Biotite gneiss	4	10
Pegmatite	1	40

The original sedimentary materials from which the sillimanite schist was derived were interpreted by Overstreet, Yates, and Griffitts (1963b) to have been fine grained and aluminous. Most likely they were shale and mudstone; this possibility is supported by the extreme scarcity of zircon in the schist. Zircon was absent from 84 of 150 samples of sillimanite schist, was present as a trace in 41 samples, and averaged only 0.0006 weight percent in 25 samples (Overstreet, Yates, and Griffitts, 1963a, table 1). Monazite, however, was absent from only 12 of the 150 samples, was present as a trace in 28 samples, and averaged 0.002 percent of the rock in 110 samples.

The original sedimentary materials from which the biotite schist formed were interpreted by Overstreet, Yates, and Griffitts (1963b) to have been graywacke and sandstone. Zircon is more common in the biotite schist than it is in the sillimanite schist, just as it is more common in sandy sediments than in shales and mudstone. Zircon was absent from 40 of 198 samples of biotite schist, was present as a grain or two in 46 samples, and averaged 0.001 weight percent in 112 samples (Overstreet, Yates, and Griffitts, 1963a, table 1). An almost identical distribution was found for monazite. Of the 198 samples of biotite schist, monazite was absent from 49, was present as a trace in 42, and averaged 0.001 percent in 107 samples.

Detrital monazite and zircon are much less common in clay- and silt-sized sediments than they are in sand-sized sediments, as has been shown in the many studies of sedimentary rocks cited through this report. In view of the sparseness of zircon in the sillimanite schist and of the tendency for fine-grained sediments to be similarly impoverished in detrital monazite, it is improbable that the monazite in the sillimanite schist consists of relict detrital grains. Evidently separate factors control the presence of zircon and monazite in this rock.

TABLE 59.—*Abundance of monazite in crystalline rocks in the monazite belt in the western Piedmont province including estimates of the contribution of the monazite to the thorium in the rock*

Rock [1] (and number of samples)	Monazite in rock (percent [1])	Average abundance of ThO_2 in monazite: Number of analyses in average	Average abundance of ThO_2 in monazite: percent [2]	Th in monazite as ppm of the rock
North Carolina:				
Shelby quadrangle:				
1. Sillimanite schist		16	4.8	
Maximum (of 150)	0.06			25.3
Average (of 110)	.002			.9
2. Biotite schist, Shelby quadrangle		31	4.8	
Maximum (of 198)	.008			3.4
Average (of 107)	.001			.5
3. Biotite gneiss		9	5.4	
Maximum (of 59)	.06			28.4
Average (of 47)	.006			2.8
4. Toluca Quartz Monzonite		23	6.1	
Maximum (of 96)	.04			21.4
Average (of 93)	.004			2.1
5. Microcline-oligoclase-quartz pegmatite		43	6.1	
Maximum (of 329)	.08			42.9
Average (of 289)	.006			3.3
Georgia:				
6. Granite south of Zetella	.017	1	[3] 4.42	6.6
Southeastern States:				
7. All monazite-bearing granitic rocks	.006	53	[3] 5.67	3.0

[1] Items 1–5 recalculated to weight percentage from volume percentage given by Overstreet, Yates, and Griffitts (1963a). Items 6 and 7 from Mertie (1953, p. 15 and 29).

[2] Thorium oxide in items 1–5 determined by K. J. Murata and H. J. Rose, Jr. (in Overstreet, Yates, and Griffitts, 1963a, table 4); in items 6 and 7 determined by F. C. Grimaldi and associates (Mertie, 1953, p. 12).

[3] Determined on detrital monazite from streams in the region; therefore, not strictly applicable.

The lesser average abundance of monazite in the biotite schist compared to its average abundance in sillimanite schist is a reversal of the normal distribution of detrital monazite in shales and sandstones. The near identity in the average abundances of monazite and zircon in the biotite schist is unusual because sandstones rarely contain these minerals in equal amounts.

The amount of monazite in the metamorphic rocks (table 59), as reported by Mertie (1953, p. 15, 29) and Overstreet, Yates, and Griffitts (1963a, table 1), does not indicate general placer concentration of heavy minerals in the sedimentary rocks. Average tenors of 0.001–0.006 percent of monazite in the crystalline rocks are an order of magnitude less than the tenors of marginal fluvial monazite placers containing about 1 pound of monazite per cubic yard of sediment. Such tenors are five orders of magnitude less than the concentrations of monazite found in beach placers like those in Brazil and India.

When the amount of thorium in the monazite is recalculated as thorium in the metamorphic rock (table 59), it is seen that the thorium contributed by the monazite is less than one-tenth of the average amount of thorium in shale, graywacke, and sandstone. Therefore, the amount of monazite in the original sediment was not enriched by placer concentration. The monazite-bearing samples of sillimanite schist contain an average of only 0.9 ppm of Th attributable to thorium in monazite, and the average attributable to monazite in biotite schist is only 0.5 ppm. The average shale has about 12 ppm of Th; the average graywacke may contain about the same amount as or less than the shale; the average sandstone probably has between 2 and 24 ppm of Th with possibly an average of 5.4 ppm (Adams and Weaver, 1958, p. 402, 413; Murray and Adams, 1958, p. 265; Rankama and Sahama, 1950, p. 573). The amount of thorium (and uranium) contributed by the monazite is also inadequate to account for the equivalent uranium determined for the samples of schist. Presumably, the indicated deficiency in thorium attributable to monazite compared to average amounts found in shales and sandstones is compensated by thorium in minerals like mica and garnet and by thorium in intergranular films in the metamorphic rocks.

The greater abundance of monazite in the metamorphosed shale and its greater radioactivity compared to the metamorphosed sandy sediment seems to correspond to the original distribution of thorium in the sedimentary rocks instead of to any original presence of detrital monazite. Very little of the thorium in common sand was said to be associated with heavy detrital minerals, and common sands contain only from one-twentieth to one-third as much thorium as shale. Offshore shales contain more thorium than nearshore sands and beach sediments (Jaffe and Hughes, 1953; Breger, 1955, p. 63; Adams and Weaver, 1958, p. 396–399, 412–413; Murray and Adams, 1958, p. 263, 267–268; Adams and others, 1958, p. 272). If the monazite in the metamorphic rocks is interpreted to be a metamorphic mineral formed from components available in the sediment and if the facies of metamorphism and concentration of components is interpreted to control the rate of nucleation of monazite during metamorphism, then the abundance of monazite should be greatest in those metamorphic rocks that initially had the most thorium and other necessary components and were metamorphosed to the highest facies. For these reasons shale metamorphosed to sillimanite schist has more monazite than isofacial biotite schist derived from sandstone and graywacke. Also for these reasons sillimanite schist throughout the world commonly contains minor accessory monazite, although shale usually lacks detrital monazite.

Specific stratigraphic units of shale or sandy sediment do not control the shape and trend of the monazite belt in the western Piedmont. The belt cuts across stratigraphic units. These relations indicate that specific sedimentary units possessing unique abundances of detrital minerals are not requisite for the formation of the belt but that some process operating later than the sedimentation produced it. Zones of regional metamorphism have been shown to cut across stratigraphic units in the Carolinas (Overstreet, Yates, and Griffitts, 1963a; Overstreet and Bell, 1960, 1962, map), and the metamorphic zone of highest facies in the western Piedmont was found to be coextensive with the monazite belt (Overstreet, 1962, p. 158–161). The trend of the belt athwart the strike of stratigraphic units is interpreted to result from the crystallization of monazite in the parts of the sedimentary rocks that were brought to the highest metamorphic facies.

Systematic regional variations in the abundance of thorium oxide in monazite from the metasedimentary rocks also indicate that the monazite formed during metamorphism. The average abundance of thorium oxide in monazite from the sillimanite schist and isofacial biotite schist in the western Piedmont is 4.80 percent, which is about the minimum usually associated with monazite from metamorphic rocks of this facies (Overstreet, 1960, p. B56). Monazite from streams underlain by rocks of the staurolite-kyanite subfacies along the flanks of the belt contains somewhat less thorium oxide than does monazite from sillimanite schist. Six samples of monazite from streams in this environment in North Carolina average 4.32 percent of ThO_2. Relict detrital grains of monazite are not likely to have been sorted into the original sedimentary rocks in such a way that their composition would vary areally and sympathetically with later progressive regional metamorphism.

Monazite from the synkinematic quartz monzonite emplaced in the schists during the main regional metamorphism contains an average of 6.1 percent of ThO_2 in 23 samples (Overstreet, Yates, and Griffitts, 1963a, table 4). An identical average abundance of thorium oxide was found for 43 samples of monazite from pegmatite genetically related to the quartz monzonite. This amount of thorium oxide resembles the lower part of the range in abundance found for monazite from granitic rocks associated with metasedimentary rocks at the sillimanite-almandine subfacies (Overstreet, 1960, p. B56).

Similarly, the relict detrital origin of magnetite in the monazite belt in the western Piedmont is contraindicated by systematic variations in trace elements. Magnetite from the sillimanitic core of the monazite belt has more lead, copper, tin, titanium, antimony, and beryllium, and less manganese and zinc than magnetite from the lower-grade metamorphic zones on the flanks of the belt (P. K. Theobald, Jr., written commun., 1961).

The apparent age of individual minerals from rocks in the monazite belt in the western Piedmont indicates that the major pulse of regional metamorphism during which the monazite was formed probably took place in Ordovician time (Overstreet, Bell, and others, 1961, p. B105). During this episode the monazite-bearing synkinematic quartz monzonite was emplaced. Subsequently, the rocks of the Piedmont were again metamorphosed, probably in Carboniferous time, and crosscutting masses of granitic rocks were locally intruded along the margins of the monazite belt in the western Piedmont.

At a very few places these young masses of granite have been found to contain minor accessory monazite accompanied by copious accessory magnetite and variably present allanite, sphene, and epidote (Dietrich, 1961, p. 9–12). These accessory minerals, except monazite, are present in very few places in the older synkinematic quartz monzonite at the core of the belt (Overstreet and Griffitts, 1955, p. 565–566), but they are characteristic of monazite-free granitic rocks between the western and eastern monazite belts in South Carolina (Overstreet and Bell, 1962) and presumably are equally common in central North Carolina. Locally, the young crosscutting granitic intrusives at the margin of the western monazite belt are nearly devoid of heavy accessory minerals. The monazite from only one of these late bodies of granite has thus far been analyzed. It is unusually rich in uranium, containing 2.34 percent of U_3O_8, an amount greater than any previously reported for monazite from the United States. It also is rich in thorium oxide; the average of three analyses is 6.6 percent of

ThO_2 (Overstreet, Yates, and Griffitts, 1963a, table 4).

The occurrences of monazite in the Blue Ridge belt and in the belt in the eastern Piedmont are also associated with narrow zones of sedimentary rocks metamorphosed to the upper amphibolite facies, but neither of these belts displays as broad and persistent a zone at this facies as the belt in the western Piedmont. In the Blue Ridge belt, sillimanite is known in discontinuous bands from Clay County on the border between North Carolina and Georgia at least as far northeastward as Mount Mitchell in Yancey County (Hash and Van Horn, 1951, pl. 9, p. 18, 36). For the Blue Ridge belt as a whole, however, most of the monazite-bearing metasedimentary rocks are at the staurolite-kyanite subfacies or at a somewhat lower subfacies. The monazite belt in the eastern Piedmont seems to be confined to a narrow zone of rocks at the staurolite-kyanite subfacies in a region prevailingly underlain by metamorphic rocks at the albite-epidote-amphibolite facies or a lower facies (Parker and Broadhurst, 1959, p. 4; Overstreet, Overstreet, and Bell, 1960; Overstreet and Bell, 1962).

The composition of monazite from the eastern belt in the Piedmont of the Carolinas was unknown in 1962. Analyses of monazite from four samples of granite exposed in the Blue Ridge belt in Macon and Jackson Counties, N.C., disclosed 4.3–5.7 percent of ThO_2 with an average of 5.0 percent (K. J. Murata, written commun., 1955). Monazite from pegmatite in Madison County was reported (Pratt, 1916, p. 27) to contain 5 percent of ThO_2, and monazite from pegmatite in Mitchell County contains 5.51 percent of ThO_2 (Bliss, 1944, p. 329). Abundances of thorium oxide on the order of 5 percent or less in monazite from granite and pegmatite resemble the amounts of thorium oxide found elsewhere in the world in monazite from granite or pegmatite associated with sedimentary rocks metamorphosed at the staurolite-kyanite subfacies (Overstreet, 1960, p. B56).

Apparent ages of minerals in the Blue Ridge belt show that monazite-bearing rocks were formed during at least two metamorphic episodes, one of which occurred in Precambrian time and the other in Ordovician time (Rodgers, 1952, p. 419–423). The age of the main metamorphism in the eastern belt is not known; however, the age of zircon in late monazite-bearing granitic plutons in the eastern belt in South Carolina is Carboniferous (Overstreet and Bell, 1962).

These observations and inferences are interpreted by the writer as showing that the monazite belts in the Carolinas were produced by regional metamorphism of sedimentary rocks. From west to east the belts seem to have been formed by successively younger orogenic episodes, although the older belts do show some effects from these younger episodes. The monazite in the metasedimentary rocks is a metamorphic mineral derived from normal components in average shales and sandstones. Sedimentary enrichment by concentration of heavy minerals prior to metamorphism is unnecessary to account for the present distribution of the monazite and cannot account for the systematic variations in its composition and abundance The composition and abundance of monazite are influenced by the metamorphic facies so that at the highest facies monazite is more abundant and richer in thorium oxide than monazite in rocks of lower facies. Monazite is more common in synkinematic granitic rocks than in the wallrocks, and it is richer in thorium oxide than is monazite from the wallrocks. The granitic rocks, however, underlie only about one-tenth of the monazite-bearing areas; therefore, they are less of a source for monazite in Recent placers than metasedimentary rocks. The generalizations regarding the relation between metamorphic facies and abundance and composition of monazite provide a basis for predicting on a world-wide scale the location of monazite occurrences and the amount of thorium oxide likely to be found in the monazite.

Individual monazite occurrences in North Carolina are discussed in geographic order from west to east.

CRYSTALLINE ROCKS AND PLACERS IN THE BLUE RIDGE PROVINCE

SPRUCE PINE DISTRICT

The Spruce Pine mica pegmatite district in parts of Mitchell, Yancey, and Avery Counties has been cited repeatedly as a source for coarse-grained monazite since 1880 when W. E. Hidden discovered well-formed crystals which were as much as 1½ inches wide and nearly an inch long at an unspecified locality in Mitchell County (Hidden, 1880, p. 85; Genth and Kerr, 1881, p. 73; Dana, E. S., 1882, p. 248; Genth, 1891, p. 77–78; Pratt, 1903, p. 180; Sterrett, 1908b, p. 285; Hafer, 1941, p. 306; Stern, 1950, p. 33). At the McKinney mine in Mitchell County scarce pieces of monazite weighing 2–3 pounds were reported to have been found (Ray, 1958, p. 296–297). Monazite, however, is actually a very uncommon mineral in the district.

The Spruce Pine district is underlain by Precambrian metasedimentary and metavolcanic rocks consisting of interlayered micaceous and hornblendic gneiss and schist, kyanitic gneiss, garnetiferous gneiss and schist, and chloritic rocks (Olson, 1944, p. 16–21). With these are various migmatitic rocks formed by the impregnation of the schists with granitic material. Intrusive into the metamorphic rocks are dunite, alaskite, and granitic pegmatite genetically related to the alaskite. Relations among the rocks are exceedingly complex. Apparently the sedimentary and volcanic rocks were metamorphosed at least once during Precambrian time and again in middle Paleozoic time. During or at the culmination of the middle Paleozoic episode, the alaskite and associated pegmatite dikes were emplaced (Bryant and Reed, 1960, p. 3; 1962, p. 164–165). The maximum metamorphic facies achieved was the staurolite-kyanite subfacies.

Monazite has been observed in the metasedimentary schists and gneisses at only a few places in the district. It is present as coarse crystals of probable pegmatitic origin in mica schist at the Deake mine in Mitchell County (Hidden, 1880, p. 85; Genth and Kerr, 1881, p. 73; Dana, E. S., 1882, p. 248; Genth, 1891, p. 77), and in garnetiferous kyanite schist at the Celo kyanite mine 4.3 miles east of Burnsville, Yancey County (Brannock, 1943). The kyanite schist is composed of biotite, muscovite, kyanite, feldspar, quartz, and graphite with minor black tourmaline, apatite, sericite, monazite, and chlorite.

Monazite occurs in alaskite at localities 1.7 miles northwest and 5.2 miles west of Spruce Pine, Mitchell County, and in either alaskite or migmatite exposed 4.2 miles west of Spruce Pine (Mertie, 1953, p. 18).

Only five pegmatite dikes out of the many hundreds of dikes in the district were reported to contain monazite. According to W. R. Griffitts (oral commun., 1960), the monazite-bearing dikes are restricted to the southeastern part of the district where alaskite is most common. In the northern and western parts of the district, monazite is generally absent from the pegmatites, but allanite is present. The only known exception to Griffitts' generalization is the Ray mica mine in the extreme western part of the district about 4 miles north-northeast of Burnsville, Yancey County, where very sparse complex euhedral crystals of monazite were said to occur in feldspar (Hidden, 1880, p. 85; Genth and Kerr, 1881, p. 73, 121; Dana, E. S., 1882, p. 248; Phillips, 1888; Genth, 1891, p. 78). Hidden lists the specific gravity of the monazite as 5.243. Schists at and near the Ray mine are very kyanitic (Genth and Kerr, 1881, p. 53). The four other monazite-bearing mica pegmatite dikes are exposed in the southeastern part of the district at the Deer Park No. 5 mine, the Deake mine, and the McKinney mine in Mitchell County, and the Number 20 mine in Yancey County.

The Deer Park No. 5 mine is about 2.5 miles west-northwest of Spruce Pine on a point of land in a sharp bend of the North Toe River (Olson, 1944, pls. 2, 3, 3A, 4). It exposes a large plagioclase and microcline-perthite pegmatite dike having a core of coarse microcline-perthite pegmatite. The dike intrudes a body of alaskite in which there are long folded septa of mica gneiss and schist interlayered with subordinate hornblende gneiss and migmatite. Resinous yellow monazite from this pegmatite has a specific gravity of 5.18. The monazite was reported to contain 0.02 percent of U_3O_8 and has an average of 5.51 percent of ThO_2 as disclosed by two analyses which showed 5.48 and 5.54 percent of ThO_2 (Bliss, 1944, p. 327, 329; Rodgers, 1952, p. 421).

The Deake mine is about a mile west-northwest of Spruce Pine in an area underlain by migmatite formed from dissemination of alaskite in mica schist and mica gneiss (Olson, 1944, pl. 1). Mica schist from the mine has long been reported to contain coarse crystals of monazite (Hidden, 1880, p. 83; Genth and Kerr, 1881, p. 73; Dana, E. S., 1882, p. 248; Genth, 1891, p. 77–78). Because of their large size these crystals are probably genetically related to the alaskite or pegmatite.

The McKinney mine is about 5.8 miles southwest of Spruce Pine in a band of mica gneiss (Olson, 1944, pl. 1). Monazite is one of the less common minerals in the pegmatite at this mine (Ray, 1958, p. 296–297), but it has been found in pieces as weighing as much as 3 pounds. Large pieces of monazite are brick red, but fine-grained monazite is yellow. Threadlike veins of an unidentified black mineral, possibly gadolinite, cut the coarse-grained monazite. Other rare minerals in the pegmatite dike are samarskite, columbite, torbernite, sphalerite, uranophane, chalcopyrite, uraninite, and beryl.

The Number 20 mine is in migmatite and alaskite exposed along Crabtree Creek in Yancey County about a mile north-northwest of the McKinney mine. Massive yellow monazite is associated with thulite and cyrtolite in the pegmatite (Ray, 1958, p. 297–299). Other scarce minerals associated with the monazite are uraninite, gummite, clarkeite, allanite, and calcite. Allanite replaces monazite at this locality (Murata and others, 1957, p. 155). The results of an analysis of the rare earth and thorium oxide precipitate from this monazite was published by Murata, Rose, Carron, and Glass (1957, p. 148), and the rare earths and thorium oxide were said to total 66.12 percent of the monazite (H. J. Rose Jr., oral commun., 1960). The published results recalculated to sum 66.12 percent show that monazite from this pegmatite contains 8.18 percent of

ThO_2, which is an unusually large percentage for monazite from the Blue Ridge:

[Analysts: Murata and Rose, U.S. Geol. Survey. Recalculated by writer from published analysis]

	Percent
La_2O_3	10. 56
CeO_2	22. 40
Pr_6O_{11}	2. 78
Nd_2O_3	12. 04
Sm_2O_3	4. 68
Gd_2O_3	2. 57
Y_2O_3	2. 91
ThO_2	8. 18
Total	66. 12

MADISON COUNTY AND HAYWOOD COUNTY

Two remarkable occurrences of monazite are known in Madison County. One of these is a monazite-bearing pegmatite at Mars Hill in the eastern part of the county, the other is in the Snowbird Group in the Ocoee Series of Precambrian age in the northwestern part of the county. A single doubtful occurrence of monazite in gneiss exposed in Haywood County has been reported.

As early as 1891, large cleavable masses of monazite, some as much as 4 inches across, had been found in the vicinity of Mars Hill, Madison County, but the specific locality was not described (Genth, 1891, p. 74). Several subsequent reports continued to refer to the large crystals and indicated that they occurred in a pegmatite dike in the Mars Hill area, but again exact localities were not cited; however, in 1913 J. H. Pratt noted that one of the masses of monazite weighed 60 pounds (Pratt, 1903, p. 181–182; 1913). In 1916 Pratt gave the first discussion of the location and geology of the Mars Hill deposit (Pratt, 1916, p. 47–48). Further brief reference was made to the locality in 1918 by Pratt (1918, p. 455), and in that same year the deposit was visited by Schaller (1933), who long afterwards published a description of the 60-pound crystal of monazite found there. Passing mention of the deposit was accorded by Drane and Stuckey (1925, p. 19), and Bryson (1927, p. 16). Interest in the deposit revived in the late 1930's when samples of the monazite were analyzed in investigations to determine the geologic age of the mineral (Marble, 1936; Lane, 1936, p. 64; 1937, p. 58; Rodgers, 1952, p. 421). Mineral collectors were apprised of the locality in 1942 (Brannock, 1942, p. 85). The following description of monazite at Mars Hill is drawn mainly from Pratt (1916) and Schaller (1933), with additional geological data from Hash and Van Horn (1951, p. 18).

The Mars Hill monazite deposit is about 3 miles southwest of Mars Hill, Madison County, on the farm formerly owned by the late Rev. N. P. M. Corn. The deposit proper is a pegmatite dike and associated pegmatite-impregnated zone, 15 feet wide or less, in what may be Cranberry Granite Gneiss of Precambrian age. Possibly part of the pegmatized zone is in a septum of layered gneiss and schist, but owing to deep weathering the rocks have not been identified with certainty. At least some of the rocks in the Mars Hill area are massive to schistose sillimanite-garnet-biotite gneiss (Hash and Van Horn, 1951, p. 18), but sillimanitic rocks have not been reported from the Corn farm. The pegmatized zone and pegmatite dike trend N. 30° E. about parallel to contacts between Cranberry Granite Gneiss and septa of layered gneiss and schist. Neither the pegmatized zone nor the dike crop out clearly, but several pits and a shaft along the probable trend disclose the zone for at least 100 feet on strike, and cleavage fragments of monazite float are scattered abundantly along the ground for several hundred feet south of the pits. Possibly several lens-shaped masses of pegmatite instead of a single dike occupy the pegmatized zone.

The exposed part of the pegmatite dike seems to be zoned: along its east side is dark-green mica as much as 1 foot thick, adjoining the mica on the west is massive quartz 1–2 feet thick, and adjacent to the quartz is the main body of the dike, which is composed chiefly of feldspar and is of unreported width. Monazite occurs in the feldspathic and micaceous parts of the dike and in the pegmatized zone in the wallrocks (Pratt, 1916, p. 47; Schaller, 1933, p. 439; Mertie, 1953, p. 18). The coarse-grained monazite occupies a layer 1–4 inches wide, but locally much wider, in the mica zone in the dike. Doubtless there are several such monazite-rich layers instead of a single continuous one. Presumably the giant crystal of monazite described by Schaller came from one of these layers in the dike; certainly most of the coarse-grained float and the lump monazite mined from the deposit came from the layer. Monazite from the feldspathic part of the dike and from the pegmatized zone in the wallrocks is relatively fine grained. According to Schaller (1933, p. 439), the layer in the mica zone contains about 37 percent of monazite:

	Percent
Monazite layer in mica zone	36. 90
Mica zone in pegmatite	1. 06
Feldspar zone in pegmatite	. 33
Pegmatized zone in country rock	. 05

Well-terminated crystals of monazite weighing 6½–12 pounds were found at the deposit soon after it was discovered, and several large cleavable masses, rough crystals, and irregular fragments of monazite have been found. The largest crystal of monazite taken from the deposit weighed almost exactly 60 pounds when it was collected, but when it was examined by Schaller in 1918 it weighed 58¾ pounds. In its present form the crystal measures 6½ inches along the *a* axis, 9½ inches along the *b* axis, and 11 inches along the *c* axis. For many years it was in the Burnham S. Colburn mineral collection at Biltmore Forest, N.C., but it was acquired by the geological museum of the University of South Carolina and at this writing (1962) is on display at Columbia, S.C. So far as is known, this is the largest monazite crystal ever discovered.

Analyses of monazite from the Corn farm near Mars Hill have shown that the monazite contains from 5.06 to 7.0 percent of ThO_2. Pratt (1916, p. 48) reported 5.06 percent of ThO_2. Schaller (1933) determined 6.06 percent of ThO_2 and observed that another analyst had found 7 percent of ThO_2. Two analyses by Marble (1936) disclosed 6.30 and 6.38 percent of ThO_2 with 0.022 and 0.019 percent of U_3O_8. Microchemical analyses by Edith Kroupa in 1936 (Lane, 1937, p. 58) showed 6.31 and 6.55 percent of ThO_2:

	Percent		*Percent*
RE_2O_3	63.29	MgO	0.15
ThO_2	[1] 6.55	PbO	.179
U_3O_8	[2] .036	MnO	.16
P_2O_5	23.44	H_2O-	.28
SiO_2	2.03	H_2O+	1.22
Al_2O_3	1.64	Insoluble residue	.40
Fe_2O_3	1.74		
CaO	.80	Total	[3] 101.91

[1] In a second determination found to be 6.31 percent.
[2] In a second determination found to be 0.042 percent.
[3] Total reported as 101.80 percent.

The monazite deposit on the Corn farm near Mars Hill was said to have been opened in 1902 by Paul S. Corn (Schaller, 1933, p. 437) and to have been worked intermittently for 2 years thereafter. Sporadic development was attempted as late as 1918. Several hundred pounds of monazite have been carried away from the deposit by visitors, but there is no record of commercial shipments.

Relict detrital monazite was observed by Oriel (1950, p. 29) in thin sections of mylonitized feldspathic sandstone, arkose, and micaceous sandstone in the Precambrian Snowbird Group of the Ocoee Series in the vicinity of Hot Springs, Madison County. Mylonites at one or more of the following localities contain monazite, but which ones specifically are monazite-bearing was not stated by Oriel: head of the east fork of the Coonpatch Branch; locality 2,800 feet north-northeast of Anderson Cemetery on Spring Creek Mountain; locality 3,800 feet due south of Mill Ridge Church; and locality in a roadcut near bench mark P58 to the southwest of Tanyard Gap on U.S. Route 25–70.

The presence of detrital monazite in the Precambrian Snowbird Group of the Ocoee Series demonstrates that the source rocks of the detrital monazite are part of the older Precambrian complex of the Blue Ridge. Therefore, some very old rocks are monazite-bearing in the Blue Ridge monazite belt.

One sample out of four samples of Precambrian gneiss and granite underlying the Ocoee Series in Haywood County was reported by Carroll, Neuman, and Jaffe (1957, p. 186) to contain possible monazite accompanied by zircon and epidote. The possible monazite is in gneiss exposed near Fines Creek.

ZIRCONIA DISTRICT

Monazite was reported in 1888 by Hidden (1888b, p. 381–382) as one of a variety of heavy minerals occurring in decomposed granitic rock exposed on the Davis land between Zirconia Station and Poinsett Spring about 4 miles from Green River Post Office, Henderson County. Zircon was especially plentiful, and xenotime and magnetite were present. The occurrence was again mentioned by Genth (1891, p. 49, 86) who reported that zircon had been mined in the Zirconia district as early as 1869 and that Hidden shipped 25 short tons of zircon from one property in the area in 1888. Thereafter intermittent mining of zircon continued through about 1916 (Olson, 1952, p. 18), but monazite was not produced.

The monazite-bearing rocks of the Zirconia pegmatite district were described by Olson (1952, p. 17–22) as syenite and quartz syenite pegmatite dikes which occur in and near a large septum of schist and gneiss in foliated granite. The septum is 0.5–1 mile wide and at least 3 miles long. It consists of biotitic and sillimanitic schists and banded feldspathic gneisses the foliation of which is athwart the trend of the septum. The dikes consist mainly of microcline with small quantities of albite and very sparse quartz. In addition to these minerals and the previously mentioned accessories, the dikes were said to contain anatase, sphene, titaniferous garnet, polycrase, allanite, auerlite, epidote, stilbite, apatite, beryl, muscovite, calcite, kaolin, and decomposed hydrated mica, which may be vermiculite. Wall zones of large dikes are as much as 15–20 feet thick and are especially rich in vermiculite. The vermiculite does not seem to be derived from alteration of the enclosing rocks, which are light-colored granitic gneisses.

The unusual concentration of zircon in the pegmatite of the Zirconia district is greater than the concentrations of zircon associated with other crystalline rocks in the State except syenite (Mertie, 1958, p. 19). Monazite, however, is absent from syenite in North Carolina and is only known in syenite pegmatite in the Zirconia district in the Blue Ridge and in syenite pegmatite at a few localities in the Piedmont.

The Zirconia district is considerably east of the Blue Ridge monazite belt as defined by occurrences of monazite in Mitchell, Yancey, Madison, and Haywood Counties. It is also somewhat west of the northwest edge of the monazite belt in the western Piedmont of North and South Carolina. The occurrence of monazite in syenite pegmatite is also unlike the usual occurrences in schists, gneisses, granitic rocks, and granitic pegmatites in the monazite belts in the Blue Ridge and western Piedmont. In geologic age the syenite pegmatite of the Zirconia district is considerably younger than the monazite-bearing rocks of these two belts. The syenite pegmatite is probably Permian in age, whereas the monazite-bearing granite pegmatites of the western Piedmont and Blue Ridge are probably no younger than Ordovician, and some monazite-bearing gneiss and schist in the Blue Ridge is of Precambrian age (Overstreet, Bell and others, 1961; Overstreet and Bell, 1962, map). The apparent age of the syenite pegmatite in the Zirconia district is the same as the apparent age of monazite-bearing granites in the South Carolina segment of the easternmost monazite belt in the Piedmont. It is therefore probable that monazite in the Zirconia district is unrelated to the geologic events responsible for the formation of monazite occurrences in the Blue Ridge and western Piedmont belts. The Zirconia occurrences are seemingly related to igneous activity that prevailed at the time of formation of the easternmost monazite belt in the Piedmont.

MACON, JACKSON, AND CLAY COUNTIES

Highly micaceous saprolite exposed in the beds of Masons Branch, Caler Fork of Cowee Creek, and other tributaries to the Little Tennessee River 5–8 miles north of Franklin in Macon County was said to contain accessory monazite (Judd and Hidden, 1899, p. 142). Concentrates panned from the saprolite contained sillimanite, staurolite, ilmenite, rutile, monazite, spinel, rhodolite garnet, corundum, gold, and sperrylite. The micaceous rocks were described as being interlayered with various mafic rocks including garnet amphibolite (called hornblende eclogite), amphibolite, and hornblende gneiss. Cutting these are mafic dikes and pegmatite. Alluvium in Masons Branch had earlier been described as monazite-bearing by Hidden and Pratt (1898a, p. 294; 1898b, p. 466), and the stream gravel was the discovery locality for the variety of garnet they named rhodolite. Other detrital heavy minerals in alluvium from Masons Branch were reported to be corundum, pleonaste, gahnite, bronzite, cordierite, kyanite, sillimanite, hornblende, staurolite, rutile, ilmenite, chromite, zircon, gold, and sperrylite. Monazite was also found in the alluvium of Caler Fork where sperrylite was first identified in North Carolina (Hidden, 1898, p. 381).

From these old reports it seems that monazite in this area occurs in some form of mica schist, possibly kyanitic, sillimanitic, or corundum-bearing. In descriptions of the geology of rhodolite deposits on Masons Mountain, situated between Masons Branch and Caler Fork, E. P. Henderson (1931, p. 563–565) and Heinrich (1950b, p. 764–770) did not report monazite as a constituent of the complex suite of mafic rocks in which the rhodolite is found, nor did Heinrich report it in the mica pegmatites and kyanite- and staurolite-bearing pegmatites associated with the rhodolite deposits. The paragenetic sequence worked out by Heinrich for the rhodolite-bearing rocks indicates that rhodolite-hypersthene gneisses were formed in an early metamorphic stage. Prior descriptions under the term "hornblende eclogite" of what is probably the same rock as the rhodolite-hypersthene gneiss and reference to the abundance of sillimanite indicate that high levels of metamorphism may have been reached in the Masons Mountain area. The regional details are, however, very imperfectly known, as are the sources and origin of the monazite.

Monazite from the Masons Mountain area forms euhedral crystals in only a few places (Hidden and Pratt, 1898b, p. 466). It occurs as minute grains that are commonly perfectly transparent, very brilliant, and yellow (Judd and Hidden, 1899, p. 147). Megascopic brown and green varieties of monazite are sparse, and a few green rough crystals as much as 0.25 inch across have been found.

The minute yellow variety of monazite was stated to contain only 0.03 percent of ThO_2, but the other components were not identified and the source of the analysis was not given (Hidden, 1898, p. 381; Judd and Hidden, 1899, p. 147). A question may exist if the material analyzed was actually monazite or was xenotime. In the original reference (Hidden, 1898, p. 381) the statement on composition was given as a footnote and in another reference Hidden and Pratt (1898b, p. 466) likened the possible abundance of thorium and uranium in the green monazite at the Masons Mountain area to that in green xenotime at Brindletown, Burke County, N.C., samples of which were analyzed by L. G. Eakins of the U.S. Geological Survey and found to contain only a trace of thorium oxide (Hidden, 1893, p. 256–257). The small amount of thorium oxide attributed to the Masons Mountain monazite is exceptional for monazite from what may possibly be an unusually plutonic environment. If the monazite formed in mica schists under the same metamorphic conditions in which rhodolite-hypersthene gneisses crystallized, then it might be expected to contain hundreds of times more thorium oxide than is reported. Some of the so-called green monazite might even be cheralite. The position of monazite in the paragenetic sequence at this locality needs to be clarified, and the composition of the monazite needs to be determined. Prior to analysis the material should be examined under unfiltered ultraviolet light by the method of Murata and Bastron (1956) to insure that xenotime is excluded.

Whiteside Granite exposed near Highlands in Macon County and at a point west of Cashiers in Jackson County was found by W. R. Griffitts (written commun., 1955) to be monazite bearing. Analyses by K. J. Murata and H. J. Rose, Jr., of the U.S. Geological Survey of four samples disclosed that it contains only moderate amounts of thorium but that it has the remarkably high average Ce/(Nd + Y) atomic ratio of 2.99 (table 60). According to Murata and associates (1953, p. 296–299; 1957, p. 150, 153, figs. 2, 5), an atomic ratio as great as 2.99 indicates very highly fractionated monazite dominated by basic rare earths, principally lanthanum and cerium with praseodymium. In a magmatic rock such monazite presumably would be formed only after the long-continued fractional precipitation of less basic rare earths had left the magna relatively enriched in lanthanum and cerium (Murata and others, 1957, p. 150). Uncertainty attaches to the origin of the Whiteside Granite, and it cannot positively be regarded as magmatic (Overstreet and Bell, 1962); hence, the monazite may not have been produced by fractional crystallization in a magma. An interesting possible explanation for the dominance of basic rare earths in monazite from the Whiteside Granite is that the monazite is of metamorphic origin, and in metamorphic differentiation the most soluble rare earths tend to migrate into the mobilized part of the metamorphosed rocks. Inasmuch as the most soluble rare earths are lanthanum, cerium, and praseodymium, it is these elements with which the monazite is enriched. Repeated episodes of metamorphism over a long period of time might be effective in producing monazite that is unusually rich in basic rare earths. Age determinations on minerals in the Whiteside Granite strongly suggest that it is a polymetamorphic rock (Jaffe and others, 1959, p. 115-116; Overstreet and Bell, 1962).

TABLE 60.—*Thorium, uranium, and rare-earth composition of monazite from Whiteside Granite exposed in Macon and Jackson Counties, N.C.*

[Quantitative spectrochemical analyses by K. J. Murata and H. J. Rose, Jr.; chemical analyses for uranium by Carmen Johnson; samples collected by W. R. Griffitts, U.S. Geol. Survey, 1955]

Lab. No.	Source of monazite	Location of samples	ThO_2	U_3O_8	Atomic ratio $\frac{Ce}{(Nd+Y)}$
			Weight percent		
144567	Muscovitic Whiteside Granite.	5 miles west of Highlands, Macon County, along U.S. Route 64.	4.3	0.13	2.77
68	Biotitic Whiteside Granite.	do	5.1	.13	2.97
69	do	Along U.S. Route 64 at north edge of Highlands.	5.2	.35	3.40
70	do	3.75 miles west of Cashiers, Jackson County, along U.S. Route 64.	5.7	.24	2.85
Average			5.0	.24	2.99

The Horse Cove region of Jackson County near the border with Macon County and about 2 miles east of Highlands was the source in the early 1900's of several monazite-bearing concentrates panned from stream deposits (Pratt and Sterrett, 1908a, p. 314).

Several fairly rich monazite placers were stated to have been found in the early 1900's by George L. English in Clay County, but the valleys are small and the occurrences were regarded as of little economic value (Pratt and Sterrett, 1908a, p. 315). The general possibility of placer deposits in the Blue Ridge, however, has not been carefully evaluated. Particularly, the possibility of fossil placers associated with old river terrace levels (Hunter, C.E., 1940, p. 101) seems to have been neglected.

CRYSTALLINE ROCKS IN THE WESTERN MONAZITE BELT IN THE PIEDMONT PROVINCE

The greatest number of reported occurrences of monazite in North Carolina are in crystalline rocks of the Piedmont in the area defined as the western monazite belt by Mertie (1953, pl. 1; Olson and Adams, 1962, map). This belt is also the region where stream placers were formerly mined for monazite. Because of the economic interest that has attached thereto, the belt in the western Piedmont has received more attention than other places where monazite has been found in the State. Monazite-bearing crystalline rocks of the belt extend southwest across North Carolina from Stokes and Surry Counties on the northeast to the border with South Carolina along the south edge of Polk, Rutherford, and Cleveland Counties. Not all rocks in the belt are monazite bearing, but very few monazite occurrences are known in the Piedmont outside this belt and the eastern belt described farther along.

Perhaps as much as 10–15 percent of the area of the belt is underlain by massive to gneissic granitic rocks mainly of granodioritic to quartz monzonitic composition. Masses of the granitic rock tend to conform to the structure of the enclosing paragneiss and paraschist, but locally they are sharply crosscutting, and generally they contain inclusions of the wallrocks. At most places the inclusions have reaction rims or other alteration. Mutual relations of the rocks have been interpreted to show that the masses of granite were formed during a minimum of two orogenic episodes. The earlier and more profound episode probably took place in Ordovician time. The younger episode is of late Paleozoic age and probably marks the close of Appalachian mountain building in this region (Overstreet and Bell, 1962).

Schist and gneiss formed from sedimentary and pyroclastic rocks are the principal components of the western monazite belt in North Carolina. The belt occupies an exceptionally well-defined zone of progressive regional metamorphism (Overstreet and Griffitts, 1955, p. 555–566; Overstreet, Cuppels, and White, 1956). The highest metamorphic facies reached is the sillimanite-almandine subfacies. Rocks of this facies form the core of the belt southwestward from the Yadkin River in the vicinity of the border between Wilkes and Iredell Counties (Hunter and White, 1946, pl. 1) to the South Carolina State line. The sillimanitic core of the belt reaches its greatest width, about 25 miles, in Cleveland and Rutherford Counties; from there it extends southwestward nearly across South Carolina. Within this core are most of the monazite occurrences known in the belt and the largest part of the monazite containing 4.5 percent of ThO_2 or more. The remainder of the occurrences, and generally ones yielding monazite with 4.5 percent of ThO_2 or less, are along the southeast and northwest flanks of the belt and in the full width of the belt northeastward from the vicinity of the Yadkin River near the border between Wilkes and Iredell Counties. In these flanking areas the metasedimentary rocks are at the staurolite-kyanite subfacies or lower metamorphic facies. The zone of closure of rocks of lower facies around the sillimanitic core of the belt in the vicinity of the Yadkin River, effectively defines the limit of known monazite placers at the time mining ceased (Pratt, 1916, pl. 1). Northeast of the northeastern end of the sillimanitic core of the belt there are few occurrences of monazite in the lower rank rocks, and these occurrences do not give rise to placers that are large or high in tenor.

STOKES COUNTY AND SURRY COUNTY

The rocks of the monazite belt in the western Piedmont of North Carolina in Stokes County and Surry County are characteristically of medium and low metamorphic facies.

The Ridgeway–Sandy Ridge pegmatite district in North Carolina and Virginia was said by Griffitts, Jahns, and Lemhke (1953, p. 143–146) to contain granitic rocks that are locally monazite bearing, but the muscovite pegmatites are barren of monazite. The southern part of the district is named after Sandy Ridge in Stokes County. The area is mainly underlain by garnetiferous muscovite schist consisting of muscovite, quartz, sodic plagioclase, biotite, and garnet, with accessory epidote, magnetite, ilmenite, sphene, tourmaline, zircon, and rutile. Biotite gneiss forms layers as much as 500 feet in thickness in the muscovite schist; it is composed of oligoclase, orthoclase, quartz, biotite, muscovite, and epidote with accessory apatite, garnet, zircon, sphene, magnetite, and pyrite. Scarce thin layers of hornblende gneiss are present, and masses of hornblende gabbro intrude the metamorphic rocks in the northeastern part of the district. Small concordant bodies of light-gray foliated quartz monzonite and quartz diorite occur throughout the district. Microcline, oligoclase, quartz, biotite, muscovite, garnet, apatite, and epidote are its principal components. Accessory minerals are zircon, magnetite, sphene, sericite, and, very locally, monazite. Monazite is not known to occur in the other rocks of the district, and specific monazite localities in the Sandy Ridge area have not been reported.

The granitic rock at five localities in and about Mount Airy, Surry County, and granite gneiss exposed 4.7 miles by road south of Dobson, Surry County, were shown by Mertie (1953, p. 18–19) to contain accessory monazite. In a detailed description of the granitic rock at Mount Airy, Dietrich (1961, p. 7–8) classed it as a postkinematic leucogranodiorite of mesozone emplacement. Dietrich (1961, p. 10) observed that the leucogranodiorite and a late magmatic dike in it contain grains of accessory monazite which are generally surrounded by thin coronalike coatings of epidote. Where the monazite is not rimmed with epidote, it occurs between plates of biotite, but even some of these monazite grains are partly coated by epidote which lies between the monazite and the biotite. Monazite grains inside of epidote rims are smaller than unrimmed particles of monazite. Some monazite grains are in contact with apatite on one side and epidote on the other. Sphene encloses magnetite, apatite, and monazite and is enclosed by epidote (Dietrich, 1961, p. 12). According to Dietrich (1961, p. 33–35), the monazite seems to have formed very early in the sequence of crystallization of the minerals in the leucogranodiorite. It was preceded only by magnetite and by the earliest-formed apatite. Some of the epidote is interpreted to be probably pyrogenic, and to this variety is assigned tentatively the epidote-forming rims on the monazite (Dietrich, 1961, p. 35).

Reconnaissance observations made by the present writer and his associates (Overstreet and Griffitts, 1955, p. 563–564) suggest that the body of leucogranodiorite at Mount Airy in its broadest relations is transgressive, postkinematic, and emplaced under less deep-seated conditions than monazite-bearing granitic rocks exposed farther southwest in the sillimanitic core of the monazite belt. The relations between monazite and epidote in the leucogranodiorite, first described in R. V. Dietrich's detailed study, are here interpreted as showing possible lack of stability of magmatic monazite under conditions of mesozonal emplacement. It is here suggested that the monazite formed early in the magma chamber, and as the body of magma moved toward its zone of emplacement and final crystallization, the pressure-temperature conditions were lowered and monazite became unstable. Incomplete reaction between monazite and the magma are inferred to have led to partial replacement of monazite by epidote, apatite, and sphene. Shallower examples of the leucogranodiorite might be expected to show more complete reaction culminating in elimination of monazite as a mineral phase, but details of the areal geology are as yet not well enough known to test this inference.

WILKES, ALEXANDER, CATAWBA, CALDWELL, BURKE AND MCDOWELL COUNTIES

In 1950 banded granitic gneiss exposed about 8 miles east of Wilkesboro, Wilkes County, was found by Mertie (1953, p. 18) to contain monazite, but detrital monazite had been discovered in the county at least as early as 1906 by D. B. Sterrett (Pratt, 1907b, p. 109). The monazite-bearing gneiss is within the sillimanite zone defined by Hunter and White (1946, p. 1) about 10 or 12 miles southwest of the northeast end of the sillimanitic core of the monazite belt.

Monazite crystals were found by W. E. Hidden about 1880 in a muscovite-rich vein in garnetiferous mica schist at Milhollands Mill in Alexander County (Genth and Kerr, 1881, p. 73; Dana, 1882, p. 247; Hidden, 1888b, p. 381; Pratt, 1903, p. 180). Accompanying the monazite and muscovite were geniculated crystals of rutile, xenotime, quartz crystals, and pseudomorphs of limonite after siderite. Most of the monazite formed very minute grains, but some particles were about 0.05 inch across, and a few splendent transparent crystals were 0.25 inch long. These large crystals, or ones from the Emerald and Hiddenite mine discussed in the following paragraphs, may have been the material displayed by Hidden (1885, p. 183) at the New Orleans World's Industrial and Cotton Centennial Exposition of 1884–85. The original site of Milhollands Mill was described by Mertie (1953, p. 8) as on Third Creek about 2.6 miles S. 30° E. from Hiddenite, Alexander County.

The Emerald and Hiddenite mine is on the Warren farm in Alexander County south of the road between Stony Point and Hiddenite and about 1.5 miles south of the latter settlement. Stony Point was W. E. Hidden's field headquarters late in 1880 when he was searching for monazite and other minerals needed for incandescent lamps. Among the monazite-bearing pegmatite dikes he examined in this area were the mineralogically unusual ones on the Warren farm, which he found to contain a scarce green variety of spodumene subsequently named hiddenite by J. L. Smith. In the late 1800's and early 1900's the dikes were exploited for hiddenite for gem use by operations at the Emerald and Hiddenite mine. Since then the locality has been noted as a source for hiddenite, but comments also have been published about splendid crystals of monazite, quartz, and rutile (Dana, 1884, p. 542; Genth, 1891, p. 86; Pratt, 1933, p. 153).

The most complete description of the pegmatite dikes at the Emerald and Hiddenite mine was given by Palache, Davidson, and Goranson (1930). According to this report the rocks in the vicinity of the mine are andesine-quartz-biotite-garnet gneiss formed by profound polymetamorphism of argillaceous sandstone. Rounded zircon grains are present in the gneiss. Average proportions of the main components are 50 percent of quartz, 30 percent of biotite, 15 percent of andesine, and 5 percent of garnet, zircon, and apatite. Prior to the last folding of the gneiss, numerous thin lit-par-lit seams of quartz-feldspar pegmatite were formed. The lit-par-lit pegmatite contains quartz, andesine, orthoclase, microline, bronzite, tourmaline, apatite, and pyrite. In many places the feldspar grains in these veinlets were granulated and drawn out into augen by late folding. Two periods of intrusion of hiddenite-bearing pegmatite followed the formation of the lit-par-lit veins and during the last monazite formed. Monazite is only found in cavities in the pegmatites. The early-formed hiddenite pegmatites consist of quartz, andesine, microcline, hiddenite, tourmaline, garnet, dumortierite, sillimanite, zircon, biotite, sericite, rutile, apatite, pyrite, and calcite.

The cavities range in size from minute druses to openings several feet in diameter (Palache and others, 1930, p. 286, 301). Some cavities occupy shear planes in the gneiss. They cut across the gneissic layering and are sharply defined. Other cavities are not sharply defined, are surrounded by altered gneiss, and may have formed from solution of parts of earlier formed pegmatite. These cavities are also lined with free-standing growths of a variety of minerals. Within both types of cavities the paragenetic sequence seems to be quartz, hiddenite and beryl, muscovite, albite, siderite and flat rhomb calcite, quartz, monazite and rutile, andularia, pyrite, and calcite followed by corrosion of practically all the minerals and some oxidation of pyrite to limonite. Minerals whose position in the sequence were not described but which were said to occur in the cavities are amethyst, holmquistite, tourmaline, garnet, nontronite, apatite, arsenopyrite, ankerite, and aragonite. Monazite occurs as tiny clear honey-yellow crystals embedded in albite or calcite or attached to walls of the cavities. Its crystals are moderately complex and nine forms were identified on them (Palache and others, 1930, p. 298). Composition of the monazite has not been reported.

A sample of granite from the Emerald and Hiddenite mine and a sample of material from the dump, possibly dominantly gneiss, were found by Mertie (1953, p. 17–18) to contain accessory monazite. Gneiss and schist in the general area of these pegmatite deposits were said to contain minor accessory monazite (Jahns and others, 1952, p. 31; Griffitts and Olson, 1953a, p. 205, 207).

A locality 3 miles east of Hiddenite, also reported as 3 miles east of the Emerald and Hiddenite mine, was the source of a brown crystal of monazite intergrown with vein quartz (Rath, 1886, p. 149–150). Very pure transparent crystals of monazite, specific gravity 5.203, from this locality were analyzed and found to have the following composition:

[Analysts: Penfield and Sperry (1888, p. 322)]

	Percent
Ce_2O_3	37.26
$(La, Di)_2O_3$	31.60
ThO_2	1.48
P_2O_5	29.32
SiO_2	.32
Loss on ignition	.17
Total	100.15

The source of the analyzed monazite was not given, but the appearance of the crystals closely resembles descriptions of monazite from veins and vugs in the Hiddenite-Stony Point area. In this connection it should be noted that detrital monazite from Third Creek at Milhollands Mill, Alexander County, was observed by Mertie (1953, p. 12) to contain 5.19 percent of ThO_2. The monazite in Third Creek most probably is derived mainly from gneiss, schist, and granite, and the well-known occurrence in veins at Milhollands Mill probably contributes scant monazite to the stream. It seems likely that monazite in veins or vugs in this area contains less thorium oxide than monazite from the wallrocks, but proof of a difference still has to be made.

A crystal of light-brown transparent monazite included in a crystal of clear quartz from an unspecified locality in Alexander County was described by Neal Yedlin (1958, p. 419). The quartz shows a distinct phantom on which the inclusion of monazite seems to rest. The monazite and quartz resemble the intergrowth described by Gerhard vom Rath (1886) from the locality 3 miles east of Hiddenite, and they are doubtless from a vug or vein.

As early as 1895 monazite was known in streams along the west edge of Catawba County, where it was derived from gneiss, augen gneiss, and schist, but specific locations of monazite-bearing rocks were not given (Nitze, 1895c; Mezger, 1895, p. 822). Monazite was also reported as an accessory mineral in granite and gneiss in pegmatite district northeast of Hickory, Catawba County, but individual occurrences were not cited (Jahns and others, 1952, p. 31, 37; Griffitts and Olson, 1953a, p. 218).

Accessory monazite has been found in granite and gneiss in the southeastern part of Caldwell County (Jahns and others, 1952, p. 31; Griffitts and Olson, 1953a, p. 218).

Burke County at the beginning of the twentieth century was one of the most productive of the monazite-producing counties, but very little information has been published about bedrock sources of the monazite although there is an extensive literature on the placers. Probably the earliest reference to monazite in the crystalline rocks in Burke County is Mezger's (1895, p. 823) observation that lenticular masses of fine-grained granite in the South Mountains near the border with Cleveland County contain 0.2–1.0 percent of monazite. No further descriptions of bedrock sources of monazite were given until 1953 when Mertie (1953, p. 17–18) listed five exposures of monazite-bearing granite and granite gneiss in the vicinity of Jacob Fork River, Pleasant Grove, and the Ramsey area in eastern Burke County. Quartz monzonite and pegmatite that crop out locally in the Piedmont to the southeast of Shortoff Mountain and north of the Catawba River in the part of Burke County northwest of Morganton commonly contain accessory monazite (Bryant and Reed, 1960, p. 5). The quartz monzonite in this area may be equivalent to the Toluca Quartz Monzonite discussed under Cleveland County.

Monazite from the crystalline rocks in Burke County has not been analyzed, but several analyses of detrital monazite from the county disclose from 2.48 to 6.68 percent of ThO_2. These analyses are listed in the section on placers, where it is shown that the low-thorium oxide monazite tends to come from streams which flow on medium-grade metamorphic rocks, northwest of the northwest boundary of the sillimanite-almandine subfacies. The thorium oxide-rich monazite commonly comes from streams underlain by rocks of the sillimanite-almandine subfacies.

Granite gneiss exposed near the McDowell County line east of Nebo contains accessory monazite (Mertie, 1953, p. 17). Many other occurrences and several analyses of monazite have been reported from McDowell County, but they are placer deposits and are discussed farther along.

RUTHERFORD COUNTY AND CLEVELAND COUNTY

Rutherford County was one of the main sites of the placer monazite industry in North Carolina during the late 1800's and early 1900's, particularly the region around Ellenboro in the east-central part of the county (Pratt, 1904c, p. 35). Accounts of monazite in crystalline rocks of the county, however, were lacking until Mertie (1953, p. 17–18) published a record of his sampling during 1945 and 1948. He reported monazite in gneiss between Ellenboro and Bostic, in granitized schist at two localities near Spindale in the central part of the county, in granite from the Gilkey area in north-central Rutherford County, and in granite at a quarry 1.5 miles west of Hollis near the east border of the county.

Concentrates from 208 samples of saprolite of crystalline rocks and 88 samples of residual soil in eastern Rutherford County were examined for monazite by R. G. Yates between 1948 and 1951. The samples of saprolite comprised 139 specimens of schist and gneiss, 44 samples of pegmatite, and 25 samples of Toluca Quartz Monzonite. Results of this study were coupled with results from similar work in Cleveland County; therefore, it is not possible to separate them according to county. The distribution of monazite was shown on a map of the Shelby topographic quadrangle (Overstreet, Yates, and Griffitts, 1963a, pl. 1) and is discussed in the following paragraphs on Cleveland County. It was found that monazite occurs in half or more of the samples of each kind of rock; 94 percent of the samples of pegmatite and 98 percent of the samples of Toluca Quartz Monzonite are monazite bearing. Sillimanite schist contains about twice as much monazite as biotite schist. Residual soil formed on these rocks has a slightly greater incidence and a generally greater amount of monazite than the rocks themselves.

Quantitative spectrochemical analyses for thorium (Dutra and Murata, 1954; Rose and others, 1954) and determinations of the Ce/(Nd + Y) ratios in 13 samples of monazite from rocks in eastern Rutherford County were made in 1955 by K. J. Murata and H.J. Rose, Jr. (written commun., 1955) of the U.S. Geological Survey. Carmen Johnson and Blanche Ingram of the Survey analyzed four of the specimens of monazite for uranium. Results of these analyses showed that monazite from eastern Rutherford County contains from 3.7 to 8.8 percent of ThO_2 and from 0.22 to 1.48 percent of U_3O_8 (table 61). The average amount of thorium oxide in eight samples of monazite from biotite schist and biotite gneiss is 4.5 percent; the average of three samples of monazite from pegmatite is 7.4 percent, and the average of two specimens of monazite from Toluca Quartz Monzonite is 6.5 percent. Except for samples from pegmatite these average abundances are on the low side of the amounts of thorium oxide usually associated with monazite from upper amphibolite facies metasedimentary rocks and associated synkinematic granitic rocks (Overstreet, 1960, p. B56). The source area of the monazite in eastern Rutherford County is well within the sillimanitic core of the monazite belt.

TABLE 61.—*Thorium, uranium, and rare-earth composition of monazite from crystalline rocks in eastern Rutherford County, N.C.*

[Quantitative spectrochemical analyses by K. J. Murata and H. J. Rose, Jr.; chemical analyses for uranium by Carmen Johnson and Blanche Ingram, U.S. Geol. Survey 1955. Symbol used: --, not determined]

Lab. No.	Source of monazite	Location	ThO_2	U_3O_8	Atomic ratio Ce/(Nd+Y)
			Weight percent		
138559	Biotite gneiss	1 mile west-northwest of Duncans Creek Church	4. 6	--	3. 50
60	do	South flank of Piney Mountain	4. 4	0. 33	2. 47
54–539SW	Toluca Quartz Monzonite	South flank of Tom Price Mountain	8. 8	--	2. 83
55–OT–100	Pegmatite	do	11. 2	--	2. 45
138543	Biotite schist	0.5 mile northeast of Hollis	4. 6	1. 48	2. 32
75	Pegmatite	0.5 mile east of Hollis	5. 4	--	2. 47
63	Biotite gneiss	East flank of Jack Moore Mountain	3. 7	--	2. 51
76	Pegmatite	do	5. 8	--	2. 27
62	Biotite gneiss	0.25 mile south of Mount Olivet Church	5. 0	. 22	3. 30
61	do	0.5 mile southeast of Mount Olivet Church	3. 8	--	2. 57
69	Toluca Quartz Monzonite	1.6 miles east of Hopewell	4. 3	. 76	2. 65
45	Biotite schist	1.5 miles southwest of Hopewell	6. 5	--	3. 55
44	do	2.3 miles south-southwest of Hopewell	5. 4	--	2. 55

The atomic ratio Ce/(Nd + Y) is discussed with a larger group of ratios determined for monazite from the part of the Shelby quadrangle in Cleveland County.

As early as 1895 augen gneiss and gneissic granite exposed in the South Mountains along the north border of Cleveland County were observed to be monazite bearing (Mezger, 1895, p. 822).

Crystalline rocks were mined for monazite at Hickory Creek and at Carpenter Knob in Cleveland County. Pegmatite-impregnated biotite schist and gneiss exposed at the L. U. Campbell monazite placer mine on Hickory Creek about 3 miles northeast of Shelby was found to contain from 0.03 to 1.10 percent of monazite. The high tenor in monazite led to an effort to mine the rock. In 1900 the British- American Monazite Co., later called the British Monazite Co., constructed a plant to crush the rock and recover monazite (Pratt, 1901, p. 31; 1907b, p. 118–119; Sterrett, 1907b, p. 1204–1205; 1908b, p. 281; Pratt and Sterrett, 1908a, p. 325; Keith and Sterrett, 1931, p. 10). After several years of mining, a shallow and irregular quarry 5–20 feet deep was opened for a length of 450 feet and a width of 24–75 feet. Rock having 0.4 percent or more of monazite was milled as ore, and no difficulty was experienced in obtaining a product consisting of 90–95 percent of monazite. Concentrates were reported to contain 7.01 percent of ThO_2 (Pratt, 1903, p. 182). If the analyzed concentrates contained 90 percent of monazite, the results of these old determinations are in remarkably good agreement with a later analysis of a pure separate of detrital monazite from Hickory Creek at the site of the Campbell mine. The pure monazite contained 7.72 percent of ThO_2 (Mertie, 1953, p. 12). Several years of operation disclosed that the amount of monazite-rich schist and gneiss was inadequate for further mining (D'Allier, 1906, p. 30), and in 1907 the company abandoned the bedrock property and sold their equipment (Pratt, 1908, p. 66). Output of the venture is not known.

The rock from which the monazite was mined is biotite schist, biotite-sillimanite schist, and graphitic biotite gneiss more or less thoroughly impregnated with pegmatite and completely recrystallized. According to Sterrett (1907b, p. 1204–1205; 1908b, p. 281–282), the layers of rock that have the most monazite possess typical augen structure owing to eye-shaped porphyroblasts of feldspar and small lenticular bodies of pegmatite which range in size from about 0.25 to 2 inches. Layers having scant pegmatite and layers wholly composed of pegmatite contain less monazite than the porphyroblastic layers in which appreciable micaceous rock remains. All gradations exist from nonporphyroblastic gneiss through porphyroblastic gneiss to pegmatite. Such gradation may be between separate layers in the rock or between parts of the same layer. The monazite was said by Sterrett almost invariably to possess crystal form with brilliant faces and sharp edges, but observation by the present writer of many hundreds of concentrates from rocks in this area shows that crystal faces and sharp edges are not present in many places on more than 10 percent of the grains, even on monazite from pegmatite. Sterrett observed that the monazite is generally free from inclusions, although he did find graphite in one crystal. Monazite is in contact with the various minerals making up the rock, but it is commonly surrounded by or included in plates of biotite and grains of quartz. Biotite foliae are not displaced around the monazite; a relation thought by Sterrett to indicate the replacement of biotite by monazite.

The relations of monazite in rocks at the British-American Monazite mine were interpreted by Sterrett (1908b, p. 284–285) as indicating "either a gathering together of the proper elements from the original rock and their formation into monazite during recrystallization, or the introduction of the proper elements from external sources, along with the materials causing pegmatization." In Sterrett's opinion the most likely source of the monazite was solutions derived from subjacent intrusive rocks, but in the first possibility he entertained, he concisely stated the gist of the view held by the present writer. Locally monazite-rich layers have certainly developed by pegmatization, as is shown in a following discussion, but the regional development of monazite-bearing rocks seems most likely to be related to the metamorphic process abandoned by Sterrett.

The other locality in Cleveland County where monazite was commercially extracted from crystalline rocks was the F. K. McClurd mine near Carpenter Knob in the extreme northeastern part of the county. Placer mining at the McClurd property disclosed weathered pegmatite-impregnated gneiss that contained about 0.3 pound of monazite per cubic yard (Sterrett, 1908b, p. 281). Saprolite of the gneiss was sluiced for monazite, and the monazite thus produced was marketed. Seemingly no notable output was obtained, because contemporary accounts of activities at the McClurd mine are brief compared to statements about the British-American Monazite Co. Of course, the sluicing of saprolite was not unusual in itself; at some placers saprolite immediately underlying fluvial gravel was customarily dug and sluiced with the gravel (Sterrett, 1908b, p. 279).

The Carpenter Knob area of Cleveland County became the focus of several later investigations into the amount of monazite in crystalline rocks. Monazite was found in five samples of quartz monzonite exposed at Acre Rock quarry and elsewhere near Toluca in this area during 1945, 1947, and 1948 by Mertie (1953, p. 17–18, 24). Subsequently, exposures at the Acre Rock quarry were cited as the type locality for the rock named Toluca Quartz Monzonite (Griffitts and Overstreet, 1952, p. 779–782), and the general occurrence of monazite in it was indicated by Griffitts and Olson (1953a, p. 207–220). The most thorough examination of the distribution of monazite in rocks of the Carpenter Knob area was made in 1952 and 1953 by J. W. Whitlow of the U.S. Geological Survey assisted in 1952 by P. E. Myers. Whitlow measured the amount of monazite in 25 pairs of samples of saprolite and residual soil from crystalline rocks exposed in the drainage basin of Knob Creek, a stream that rises on Carpenter Knob. The samples of residual soil were taken from positions immediately overlying samples of saprolite except for two which were unfavorably situated and had to be collected some tens of feet from the saprolite. According to Whitlow (written commun., 1954) saprolite with the most monazite is from Toluca Quartz Monazite and that with the least is from biotite schist (table 62). Monazite in the residual soil averages about three to four times the amount in saprolite, and locally saprolite with unobservable amounts of monazite forms residual soil that has a small quantity of monazite. The two unfavorably situated pairs of samples included soils with less monazite than the underlying saprolite. This reversal in the usual pattern of residual enrichment was attributed to sampling error.

Elsewhere in Cleveland County exposures of monazite-bearing rocks, principally Toluca Quartz Monzonite, observed by Mertie (1953, p. 17–18) between 1945 and 1948 include five localities in the Fallston area, one in the vicinity of Lawndale, two near Casar, one near Mooresboro, and four along tributaries to Brushy Creek northwest of Shelby.

The amount of monazite in the crystalline rocks of the Shelby quadrangle, which covers 246 square miles in central and western Cleveland County and eastern Rutherford County, was investigated between 1948 and 1951 by R. G. Yates and associates of the U.S. Geological Survey (Overstreet, Yates, and Griffitts, 1963a). Heavy-mineral concentrates were panned from 1,241 samples of saprolite representing the main lithologic units in the quadrangle, 5 samples of milled vein quartz, and 300 samples of residual soil. The kinds and amounts of resistate heavy minerals were

TABLE 62.—*Amount of monazite in saprolite and residual soil in the drainage basin of Knob Creek, Cleveland County, N.C.*

[Tenors computed by J. W. Whitlow (written commun., 1954) from concentrates analyzed mineralogically by M. N. Girhard, H. B. Groom, Jr., R. P. Marquiss, C. J. Spengler, Jerome Stone, and E. J. Young]

Saprolite		Residual soil	
Lab. No.	Monazite (lb per cu yd)	Lab. No.	Monazite (lb per cu yd)
Toluca Quartz Monzonite			
109614	0.16	109605	0.19
98942	.51	31	1.16
114332	.05	33	.31
37	.13	38	.20
62	.11	63	.18
69	.11	70	.55
72	.10	73	.39
Average	.17	Average	.43
Biotite Gneiss			
88529	0.25	88530	0.42
35	.13	36	.87
114374	.05	114375	.04
80	.01	109699	.09
82	.03	114383	.08
Average	.09	Average	.30
Biotite Schist			
114334	0.19	114335	0.23
39	.01	40	.23
41	.01	42	.27
45	------	46	.05
52	.01	53	.04
Average	.04	Average	.16
Sillimanite Schist			
114343	0.03	114344	0.24
48	Trace	49	.05
50	------	51	.07
54	.13	55	.25
56	.05	57	.23
59	.04	60	.58
64	.12	65	.27
67	.24	68	.09
Average	.08	Average	.22

determined in the concentrates. About two-thirds of the soil samples, all the vein quartz, and 1,033 concentrates from saprolite came from the part of the quadrangle in Cleveland County, but results of the study were tabulated for the quadrangle as a whole; therefore, they cannot be separated by county. Concentrates were panned from saprolite of Toluca Quartz Monzonite, microcline-oligoclase-quartz pegmatite genetically related to the Toluca, biotite gneiss, biotite schist, biotite schist impregnated with pegmatite, sillimanite schist, and sillimanite schist impregnated with

TABLE 63.—*Estimated abundance of monazite in crystalline rocks in the Shelby quadrangle, Cleveland and Rutherford Counties, N.C.*

[Recalculated from Overstreet, Yates, and Griffitts (1963, table 1)]

	Number of concentrates			Monazite as weight percentage of host rock in samples giving concentrates with 1 percent or more monazite		
	Total examined	Monazite absent	Monazite less than 1 percent of concentrate	Minimum	Maximum	Average
Toluca Quartz Monzonite	96	1	2	0. 00002	0. 04	0. 004
Microcline-oligoclase-quartz-pegmatite	329	18	22	. 00002	. 08	. 006
Biotite gneiss	59	6	6	. 00002	. 06	. 006
Biotite schist	198	49	42	. 00002	. 008	. 001
Biotite schist and pegmatite	303	46	31	. 00002	. 04	. 004
Sillimanite schist	150	12	28	. 00008	. 06	. 002
Sillimanite schist and pegmatite	106	4	13	. 00002	. 01	. 002
Vein quartz	5	3	1			. 01

pegmatite. In the original tabulations the amounts of heavy minerals were estimated as volume percentages of the saprolite, but in table 63 monazite is recalculated to weight percentage of the rock.

The pegmatite-bearing rocks are intimate mixtures of schist and all degrees of lit-par-lit layering of microcline-oligoclase-quartz pegmatite. The pegmatite-bearing schists occur as well-defined zones mostly peripheral to masses of Toluca Quartz Monzonite, and the pegmatite has been interpreted to be a differentiate from the Toluca (Overstreet, Yates, and Griffitts, 1963b). Owing to the relatively large average amount of monazite in pegmatite and the high percentage of bodies of pegmatite that contain monazite (88 percent), schist impregnated with pegmatite is more commonly monazite bearing than pegmatite-free schist. Biotite schist permeated with pegmatite contains on the average of four times as much monazite as biotite schist lacking pegmatite. The presence of pegmatite does not seem to increase the amount of monazite in sillimanite schist, but it does increase the frequency with which samples of the schist are monazite bearing. Monazite occurs in more than trace amounts (1 percent of the concentrate or more) in 63 percent of samples of sillimanite schist and 54 percent of samples of biotite schist, but where pegmatite is present the percentage of monazite-bearing samples increases to 83 percent for the sillimanite schist and 75 percent for the biotite schist. Greater amounts of monazite in the lit-par-lit schists may also be in part caused by increase in the number of centers of crystallization of metamorphic monazite resulting from local geothermal rise in schists adjacent to pegmatite and quartz monzonite (Overstreet, Yates, and Griffitts, 1963a).

The estimated abundance and distribution of monazite in the metasedimentary rocks was shown by contours on a map of the Shelby quadrangle (Overstreet, Yates, and Griffitts, 1963a, pl. 1). The main trend of high-value contours for monazite was found to occupy a broad arcuate zone that extends northward from Boiling Springs to Lattimore in Cleveland County, thence northwest toward Jack Moore Mountain in Rutherford County. The zone approximately follows an area underlain by the thickest sequence of sillimanite schist in the quadrangle. A narrow and well-defined zone occupied by high-value contours for monazite is parallel and east of the main monazite high. It leads northeastward through Cleveland County from Poplar Springs Church by way of Dover Mill to Zion Church, thence northwestward by Ramseur School to the First Broad River 2 miles northeast of Polkville. This high corresponds to a narrow band of sillimanite schist and an adjacent band of biotite schist. Local monazite highs coincide with either sillimanite schist or biotite schist around several sills of Toluca Quartz Monzonite, of which the most noteworthy high is between Fallston and Flat Rock School a few miles south of Carpenter Knob and Toluca.

The local highs seem to be related to migmatization of wallrock schist by lit-par-lit introduction of monazite-bearing quartz monzonite and pegmatite. The two major zones of monazite highs are clearly related to monazite in sillimanite schist. As was stated in the section on hypotheses of origin, the writer interprets the monazite in the unintruded schists to be a metamorphic mineral formed when the sedimentary rocks were metamorphosed to the sillimanite-almandine subfacies.

The average amount of thorium oxide in monazite from 16 samples of sillimanite schist in the part of Shelby quadrangle in Cleveland County was determined by Murata and Rose of the U.S. Geological Survey to be 4.7 percent (Overstreet, Yates, and Griffitts, 1963a, table 4). A nearly identical average was found for 28 samples of biotite schist in the part of the quadrangle in Cleveland County (table 64), and, if the three samples from Rutherford County (table 61) are added, the average amount of thorium oxide in monazite from biotite schist is virtually identical to that of monazite from sillimanite schist in the quadrangle. Virtually identical averages were found for the atomic ratio Ce/(Nd + Y) of monazite from sillimanite schist and monazite from biotite schist (table 64). If the ratios found for monazite from biotite schist in Rutherford County are included and the two unusually high ratios dropped (3.55 for a sample from Rutherford County and 4.25 for a sample from Cleveland County), the average of 29 samples of monazite from biotite schist is 2.48. The great similarity in the average amount of thorium oxide and the atomic ratios is interpreted by the writer to indicate that monazite formed under similar conditions in both types of schist. A possible interpretation of the significance of the average atomic ratio is discussed a little farther along after the ratios for monazite from the other rocks has been discussed.

TABLE 64.—*Thorium and rare-earth composition of monazite from saprolite of sillimanite schist and biotite schist exposed in the Shelby quadrangle in Cleveland County, N.C.*

[Quantitative spectrochemical analyses by K. J. Murata and H. J. Rose, Jr., U.S. Geol. Survey, 1955]

Lab. No.	Location	ThO_2 (percent)	Atomic ratio Ce/(Nd+Y)
	Sillimanite schist		
138526	4.2 miles north-northeast of Polkville	9.0	2.30
27	0.4 mile north-northeast of Pleasant Hill Church.	4.8	2.32
28	3 miles north of Polkville	4.0	2.40
29	2.4 miles west of Polkville	4.2	2.65
30	1.8 miles northeast of Lattimore	4.8	2.55
31	1.7 miles east-southeast of Lattimore	4.2	2.47
32	3 miles south of Polkville	3.4	2.35
33	1.1 miles west-northwest of Lattimore	4.8	2.65
34	2 miles north of Lattimore	5.8	2.57
35	1.3 miles northwest of Zion Church	3.4	2.51
36	1 mile southeast of Double Shoals	4.8	2.50
37	1.8 miles south-southwest of Lattimore	4.6	2.47
38	1.5 miles north-northeast of Boiling Springs	4.5	2.55
39	1.5 miles southwest of Shelby	3.9	2.45
40	1.3 miles southeast of Shelby	5.1	2.63
139893	Dover Mill	4.3	2.57
Average		4.7	2.50
	Biotite schist		
135562	Dover Mill	4.6	2.34
67	do	4.0	2.35
68	do	4.2	2.34
69	do	4.0	2.34
70A	Cadish Church (Lincolnton quad.)	4.8	2.32
138541	0.5 mile northwest of Kistler Union Church	6.9	2.35
42	3.5 miles northwest of Polkville	4.6	2.30
46	Mooresboro	5.3	2.77
47	3 miles north of Dover Mill	6.3	2.63
48	3.9 miles north-northwest of Dover Mill	5.1	2.33
49	4.3 miles northwest of Dover Mill	4.4	2.30
50	2 miles west-northwest of Dover Mill	4.8	2.40
51	1.3 miles northeast of Lattimore	4.6	2.37
52	1.3 miles east-southeast of Lattimore	4.6	2.87
53	4.3 miles northeast of Lattimore	4.4	2.60
54	0.6 mile east of Lattimore	5.0	2.75
55	0.4 mile north of Lattimore	3.2	2.57
56	0.8 mile northeast of Boiling Springs	4.3	2.45
57	2.8 miles east-northeast of Boiling Springs	4.3	2.60
139894	Dover Mill	6.2	2.45
98	Cadish Church (Lincolnton quad.)	2.1	4.25
139901	do	4.8	2.67
05	1.5 miles southwest of Lawndale	3.7	2.20
16	do	5.1	2.71
17	do	6.0	2.35
18	do	3.9	2.92
50-W-115(8)	1.7 miles north of Lattimore	5.3	2.41
50-W-140S	4.2 miles northeast of Lattimore	5.6	2.44
Average		4.8	[1] 2.49

[1] The unusual ratio of sample 139898 not included.

A little information is available about the amount of U_3O_8 in monazite from the schists. Monazite from sillimanite schist exposed 0.4 mile north of Pleasant Hill Church in Cleveland County was found by Carmen Johnson and Blanche Ingram (written commun., 1955) of the U.S. Geological Survey to contain 0.45 percent of U_3O_8. Monazite from biotite schist at a locality 0.5 mile northwest of Kistler Union Church in Cleveland County was shown by Johnson and Ingram to contain 0.29 percent of U_3O_8. No relation has been discerned between the amount of uranium in the monazite and the rocks in which the monazite occurs.

Biotite gneiss formed by high-grade metamorphism of graywacke and volcanic rocks, possibly dacite, occurs close to sills of Toluca Quartz Monzonite in the Shelby quadrangle (Overstreet and Griffitts, 1962, map; Overstreet, Yates and Griffitts, 1963b). The gneiss is coarse grained and rich in microcline. At some places it seems to have been feldspathized by the quartz monzonite, but the actual origin of the rock is obscure. Monazite from the gneiss tends to be intermediate in composition between that from schists and that from Toluca Quartz Monzonite and pegmatite. Nine samples of monazite from the gneiss have been analyzed and found to average 5.4 percent of ThO_2 (Overstreet, Yates, and Griffitts, 1963a, table 4). Six of these samples have an average atomic ratio Ce/(Nd +Y) of 2.57 (K. J. Murata and H. J. Rose, Jr., written commun., 1955), but the other three have individual ratios of 3.10, 3.30, and 3.50, thereby raising the group average to 2.81. Five of the samples came from the part of the quadrangle in Rutherford County, and their composition is given in table 61. Four are from Cleveland County. They are richer in thorium oxide and have a larger atomic ratio (table 65) than monazite from biotite gneiss in Rutherford County, possibly because the gneiss in Cleveland County has been altered by Toluca Quartz Monzonite. Each of the sampled layers of gneiss in Cleveland County is in contact with sills of quartz monzonite. In its high content of thorium the monazite from biotite gneiss in Cleveland County is more like monazite from pegmatite-impregnated schist and gneiss in the quarry of the British Monazite Co. at the old Campbell mine on Hickory Creek than it is like monazite from unpegmatized schists.

The percentage of thorium oxide (Dutra and Murata, 1954) and the atomic ratios have been determined by K. J. Murata and Harry Rose, Jr., of the U.S. Geological Survey, for 23 samples of monazite from Toluca Quartz Monzonite and for 43 samples from pegmatite exposed in the Shelby quadrangle and vicinity. Results of this work disclosed that monazite from the two rocks has identical averages of 6.1 percent of ThO_2 (Overstreet, Yates, and Griffitts, 1963a, table 4). Average atomic ratios of Ce/(Nd+Y) are slightly different: the ratio for 23 samples of monazite from the Toluca is 2.54 and for 43 samples of pegmatite is 2.60. From the quartz monzonite 21 samples were taken at localities in Cleveland County, and from the pegmatite 40 were taken (table 66); they have virtually identical average amounts of thorium oxide and atomic ratios as the complete suite of samples from the quadrangle. For the single sample of monazite from a quartz vein the tenor in thorium oxide is identical to that of monazite from the quartz monzonite and pegmatite, but the atomic ratio is less

TABLE 65.—*Thorium and rare-earth composition of monazite from saprolite of biotite gneiss in Cleveland County, N.C.*

[Quantitative spectrochemical analyses by K. J. Murata and H. J. Rose, Jr., U.S. Geol. Survey, in 1955]

Lab. No.	Location	ThO_2 (percent)	Atomic ratio Ce/(Nd+Y)
138558	1 mile northeast of Kistler Union Church	6.7	2.50
564	Boiling Springs	6.2	3.10
565	4 miles southwest of Shelby	6.0	2.80
139902	Cadish Church (Lincolnton quad.)	8.8	2.57
Average		6.9	[1] 2.62

[1] The unusual ratio of sample 138564 not included.

TABLE 66.—*Thorium and rare-earth composition of monazite from saprolite of Toluca Quartz Monzonite and microcline-oligoclase-quartz pegmatite and from unweathered vein quartz exposed in Cleveland County, N.C.*

[Quantitative spectrochemical analyses by K. J. Murata and H. J. Rose, Jr., U.S. Geol. Survey, in 1955]

Lab. No.	Location	ThO_2 (percent)	Atomic ratio Ce/(Nd+Y)
	Toluca Quartz Monzonite		
135570B	Cadish Church (Lincolnton quad.)	5.4	2.47
70C	do	6.7	2.78
70D	do	6.1	2.24
70E	do	5.7	2.60
70F	do	5.8	2.53
70G	do	6.0	2.55
70H	do	6.5	2.75
138566	1.1 miles northeast of Kistler Union Church	6.2	2.63
66A	do	5.7	2.60
66B	do	6.5	2.63
67	1.3 miles north-northeast of Kistler Union Church.	7.3	2.30
68	0.6 mile east-southeast of Pleasant Hill Church.	7.2	2.20
70	2.7 miles south-southwest of Polkville	4.3	2.33
71	3 miles east-northeast of Lattimore	5.1	2.60
139895	Cadish Church (Lincolnton quad.)	6.7	2.55
96	do	6.6	2.45
97	do	6.4	2.80
99	do	6.6	2.57
139900	do	6.6	2.57
03	do	6.1	2.55
54-537SW[1]	Quarry at Acre Rock, 1.7 miles southwest of Toluca (Casar quad.).	5.3	2.26
Average		6.1	2.52

See footnotes at end of table.

TABLE 66.—*Thorium and rare-earth composition of monazite from saprolite of Toluca Quartz Monzonite and microcline-oligoclase-quartz pegmatite and from unweathered vein quartz exposed in Cleveland County, N.C.*—Continued.

Lab. No.	Location	ThO_2 (percent)	Atomic ratio Ce/(Nd+Y)
	Microcline-oligoclase-quartz pegmatite		
135563	Dover Mill	5.2	2.36
64	do	5.5	2.42
65	do	5.6	2.41
66	do	5.1	2.45
138572	0.7 mile southwest of Kistler Union Church	7.6	2.75
73	1.4 miles east of Kistler Union Church	8.5	2.30
74	1.9 miles east of Polkville	5.7	2.80
77	1.4 miles southwest of Zion Church	6.7	2.75
78	2.2 miles west-northwest of Dover Mill	5.3	2.60
79	2 miles east-southeast of Lattimore	7.1	2.75
80	1.3 miles northwest of Zion Church	4.1	2.80
81	0.2 mile north of Double Shoals	7.3	2.47
82	1.8 miles south-southwest of Zion Church	6.7	2.60
83	2.4 miles east of Boiling Springs	3.8	2.50
139892	Dover Mill	4.9	2.65
139906	1.5 miles southwest of Lawndale	7.2	2.60
07	do	6.9	2.70
07	do	5.8	2.78
07	do	6.8	2.79
08	do	6.8	2.77
09	do	6.5	2.77
10	do	6.3	2.60
11	do	5.3	2.60
12	do	6.3	2.72
13	do	6.0	2.74
14	do	5.9	2.80
15	do	6.0	2.55
19	0.5 mile northwest of Double Shoals	5.8	2.90
20	do	6.0	3.20
50-W-115P	1.8 miles north of Lattimore	5.4	2.52
50-W-115Q	do	5.0	2.45
50-W-115R	do	5.7	2.54
50-W-115S	do	5.6	2.37
50-W-115T	do	5.2	2.27
50-W-115U	do	5.2	2.46
50-W-115W	do	5.3	2.51
50-W-115X	do	5.4	2.66
50-W-140A	2.8 miles west-northwest of Zion Church	5.7	2.70
50-W-140B	do	7.0	2.60
54-538SW [1]	Quarry at Acre Rock, 1.7 miles southwest of Toluca (Casar quad.)	6.4	2.50
Average		6.0	[2] 2.60
	Vein quartz		
138377 [1]	2. miles northeast of Boiling Springs	6.1	2.27

[1] Unweathered sample.
[2] The unusual ratio of sample 139920 not included.

than the average ratios for monazite from the other rocks. The atomic ratios probably provide evidence as to the origin of monazite in the schists, quartz monzonite, and pegmatite. The ratio of the sample from vein quartz does not fit the pattern shown by the monazite from the main rock units, but it is very similar to the ratios of monazite from the Cherryville Quartz Monzonite, a rock that crops out to the east of the quadrangle.

The composition of rare earths plus thorium oxide precipitated from solutions of seven samples of monazite from Rutherford County and Cleveland County was determined spectrochemically by Murata, Rose, Carron, and Glass (1957, p. 148). In table 67 the values published by Murata, Rose, Carron, and Glass have been recalculated to percentages of oxides in

TABLE 67.—*Chemical analyses of rare earth plus thoria precipitates from monazite, Rutherford and Cleveland Counties, N.C.*

[Analyses recalculated from Murata, Rose, Carron, and Glass (1957, p. 148)]

	Rutherford County				Cleveland County		
	138544	138560	54-539SW	55-OT-100	138538	54-537SW	54-538SW
La_2O_3	14.8	16.2	14.8	10.1	15.3	13.9	14.1
CeO_2	30.0	33.7	30.1	23.3	30.2	29.5	29.9
Pr_6O_{11}	3.0	2.9	2.8	2.9	2.8	3.4	3.2
Nd_2O_3	11.3	9.6	9.4	9.5	11.7	12.1	11.1
Sm_2O_3	1.6	.8	1.2	2.6	1.6	2.2	2.1
Gd_2O_3	.5	.3	.5	2.1	1.3	.8	.7
Y_2O_3	2.4	.1	.6	2.3	.9	.4	.4
ThO_2	5.4	4.4	8.8	11.2	4.5	5.3	6.4
Total	69.0	68.0	68.2	64.0	68.3	67.6	67.9

138544. Biotite schist.
138560. Biotite gneiss.
54-539SW. Toluca Quartz Monzonite.
55-OT-100. Pegmatite.
138538. Sillimanite schist.
54-537SW. Toluca Quartz Monzonite.
54-538SW. Pegmatite.

monazite from data furnished by H. J. Rose, Jr. (written commun., 1959).

The content of thorium oxide and the Ce/(Nd+Y) atomic ratios are less in monazite from schists than in monazite from quartz monzonite in the parts of Rutherford County and Cleveland County covered by the Shelby quadrangle:

Source of monazite	Number of analyses of monazite	ThO_2 (Avg percent)	Atomic ratio Ce/(Nd+Y)
Biotite schist	31	4.8	[1] 2.48
Sillimanite schist	16	4.8	2.49
Biotite gneiss	9	5.4	[2] 2.57
Toluca Quartz Monzonite	23	6.1	2.54
Pegmatite	43	6.1	2.60
Quartz vein	1	6.1	2.27

[1] Average of 29 analyses.
[2] Average of 6 analyses.

Rare earths in monazite from the pegmatite, as indicated by the atomic ratios, are more highly fractionated than rare earths in monazite from the quartz monzonite. Systematic variations in rare earths in monazite from the quartz monzonite and pegmatite have been tentatively attributed by Murata and associates (1953, p. 296–299; 1957, p. 148–151) to repeated fractional precipitation of the rare-earth elements in a differentiating magma in which substantial but undetermined parts of the rare earths are probably captured by other minerals such as xenotime, biotite, and garnet. Biotite and garnet from the Toluca Quartz Monzonite were found by K. J. Murata (written commun., 1954) to contain lanthanum and yttrium. Both the biotite and garnet contained more yttrium in relation to lanthanum than monazite from the Toluca. Murata interpreted these relations to indicate that a major factor in the fractionation of rare earths in nature was probably the selective deposition of yttrium earths in silicate minerals; this deposition resulted in the enrichment of residual fluid in cerium as successive rocks differentiated out of the magma (K. J. Murata, written commun., 1954).

Monazite from the schists has smaller Ce/(Nd+Y) atomic ratios than monazite from the quartz monzonite and pegmatite, and this fact indicates that the monazite in the schists has on the average more of the less basic and less soluble (Carron and others, 1958, p. 268) rare earths than the monazite in the quartz monzonite and pegmatite. These less basic elements contribute to a contraction of the unit cell of the monazite (Murata and others, 1957, p. 150); thus, monazite in the schists has a smaller unit cell than monazite in the quartz monzonite and pegmatite. If monazite in the schists had been deposited by solutions derived from the quartz monzonite, it might be expected that these solutions would be more highly fractionated than the quartz monzonite and that the monazite deposited by them would have larger average atomic ratios than monazite from the quartz monzonite; for the same reasons monazite in the schist would be expected to have a larger unit cell than monazite in the quartz monzonite.

An interesting possible explanation for these seeming conflicts is that the regional metamorphism which formed the schists may also have produced the quartz monzonite as a metamorphic differentiate. As exposed in the Shelby quadrangle, the Toluca Quartz Monzonite consists of concordant intrusive bodies which contain sparse altered inclusions of the wallrocks (Overstreet, Yates, and Griffitts, 1963a). It was formed at depth and migrated upward. That the Toluca Quartz Monzonite could migrate and the schists could not may be important in the control of the composition of the monazite and the size of its unit cell. Under the influence of high-grade regional metamorphism possibly the more basic rare earths (lanthanum, cerium, and praseodymium), which are most soluble, were preferentially mobilized and migrated with components that were surplus to the metamorphic mineral phases of the schists. The less basic rare earths (neodymium, gadolinium, and yttrium), which are less soluble, were preferentially retained in the schists. Crystallization of the more basic rare earths in the mobilized parts of the metamorphic rocks gave rare-earth-bearing biotite with relatively more yttrium than lanthanum and also monazite with a large Ce/(Nd+Y) atomic ratio and large unit cell. Crystallization of the less basic rare earths remaining in the unmobilized schists gave monazite with a small Ce/(Nd+Y) atomic ratio and small unit cell. Relations of the rare earths in the biotite and garnet in the schists are not known. Monazite with large atomic ratio and unit cell seems to be compatible with a relatively mobile phase, whereas monazite with small atomic ratio and unit cell seems to be compatible with the static phase of the metamorphic rocks. Differentiation and fractional crystallization in the mobile phase probably would lead to pegmatites having monazite with highly fractionated rare earths.

Monazite from the biotite gneiss possesses hybrid average abundance of thorium oxide and Ce/(Nd+Y) atomic ratio that places it between monazite from the schists and monazite from the pegmatite related to the Toluca Quartz Monzonite. The origin and relations of the biotite gneiss are poorly understood, and no satisfactory explanation is available for the composition of the monazite. At most places the gneiss seems to have been altered by the Toluca and pegmatites related to the Toluca. Possibly monazite from the gneiss is polygenetic, being in part formed in place in the gneiss and in part crystallized from stringers of pegmatite and Toluca Quartz Monzonite.

The single sample of monazite from vein quartz contains identically the same amount of thorium oxide as the average of monazite from the Toluca Quartz Monzonite and pegmatite related to the Toluca. Its Ce/(Nd+Y) ratio of 2.27 is very different from the average for monazite from the Toluca and pegmatite, although about six individual analyses in the group disclosed similar ratios. Without other analyses of monazite from quartz veins in the area it is not certain if this ratio is unusually low for monazite from these veins or if it is about average. Because the vein also contains accessory rutile and zircon that resemble those minerals in Toluca Quartz Monzonite the vein was interpreted to be genetically related to the Toluca (Overstreet, Yates, and Griffitts, 1963a). The amount of thorium oxide and the atomic ratio, however, closely resemble those of monazite from the much younger Cherryville Quartz Monzonite which crops out to the east of the Shelby quadrangle along and outside the east edge of the western monazite belt (Griffitts and Overstreet, 1952, p. 783–786). It may be possible that this quartz vein was derived from the Cherryville.

The Cherryville Quartz Monzonite is a crosscutting pluton which is partly outside the east edge of the western monazite belt, but because of its close relation to the belt it is mentioned here. Most specimens of the Cherryville Quartz Monzonite and mica-bearing pegmatites related to it lack monazite (Jahns and others, 1952, p. 31; Griffitts and Olson, 1953a, p. 218), but in eastern Cleveland County two samples from a locality in the Lincolnton quadrangle and one from the Kings Mountain quadrangle were found to have monazite (Overstreet, Yates, and Griffitts, 1963a, table 4). Analyses of the three specimens of monazite disclosed an average of 6.4 percent of ThO_2 and an average Ce/(Nd+Y) atomic ratio of 2.34 (table 68). The single determination of uranium showed that monazite from the Buffalo Creek locality has more uranium than any other in the United States.

Pegmatite probably related to the Cherryville Quartz Monzonite and exposed 5.6 miles east of Buffalo Creek on the western outskirts of Kings Mountain, Cleveland County, contains monazite (Mertie, 1953, p. 17).

The pegmatites of the tin-spodumene belt in Cleveland, Gaston, and Lincoln Counties are for the most part barren of monazite and are generally thought to lie just to the east of the east edge of the monazite belt (Jahns and others, 1952, p. 31). Inasmuch as they are closely associated spatially with and may be genetically related to the Cherryville Quartz Monzonite, they are mentioned here. The spodumene pegmatite mined by the Foote Mineral Co. just south of Kings Mountain in Cleveland County was said to contain sparse monazite which was recovered as a byproduct along with cassiterite, columbite, pyrrhotite, pyrite, and rutile (Hudspeth, 1952). Apparently these minerals are fine grained and disseminated through the pegmatite. They are estimated by Hudspeth to make up altogether about 0.2 percent of the spodumene ore. Beryl, apatite, and tourmaline are also present in the pegmatite.

LINCOLN COUNTY AND GASTON COUNTY

Monazite is an accessory mineral in Toluca Quartz Monzonite exposed in the extreme northwest corner of Lincoln County (Overstreet, Whitlow, White, and Griffitts, 1963). None of the occurrences in the Toluca is a possible commercial source of monazite, but placers in streams rising on the quartz monzonite and schists

TABLE 68.—*Thorium, uranium, and rare-earth composition of monazite from the Cherryville Quartz Monzonite exposed in Cleveland County, N.C.*

[Quantitative spectrochemical analyses for thorium and determination of Ce/(Nd+Y) atomic ratio by K. J. Murata and H. J. Rose, Jr.; chemical analysis for uranium by Blanche Ingram, U.S. Geol. Survey, in 1954–55. Symbol used: —, not determined]

Lab. No.	Location	ThO_2 (percent)	U_3O_8 (percent)	Atomic ratio Ce/(Nd+Y)
53-BE-3 [1]	Buffalo Creek 2.3 miles east-southeast of Elizabeth Church.	5.6	2.34	2.36
135556 [2]	do	6.6	—	2.19
49 [1]	Grover	6.9	—	2.49
Average		6.4	—	2.34

[1] Saprolite.
[2] Unweathered rock.

in this area were mined for detrital monazite in the late 1800's and early 1900's.

The Cherryville area in northwestern Gaston County has been cited as a source for monazite, but details have not been given (Drane and Stuckey, 1925, p. 19; Bryson, 1927, p. 15–16). The area is the type locality for the Cherryville Quartz Monzonite which contains few accessory minerals and at Cherryville is not known to be monazite-bearing (Griffitts and Overstreet, 1952, p. 783–786). The references to Cherryville may relate to monazite placers formerly worked several miles to the west of the town (Sterrett, 1908b, p. 274), or Drane and Stuckey may have found a place where the Cherryville Quartz Monzonite was monazite bearing. Inasmuch as two such localities are known in Cleveland County, it is possible that others are present in Gaston County and Lincoln County. In general, however, the pluton of Cherryville Quartz Monzonite lies on the east side of and outside the western monazite belt in the Piedmont.

OUTLYING LOCALITIES IN THE PIEDMONT PROVINCE BETWEEN THE WESTERN AND EASTERN MONAZITE BELTS

Several scattered occurrences of monazite have been reported from that part of the Piedmont physiographic province of North Carolina that is between the western and eastern monazite belts as defined by Mertie (1953, pl. 1). At some localities the monazite is present in crystalline rocks. Elsewhere it is found in stream sediments and may have been transported many miles to its present site. Because the geology of the few detrital deposits in these outlying deposits is closely related to the geology of the crystalline rocks in the Piedmont, they are here discussed with occurrences of monazite in crystalline rocks.

GASTON COUNTY

Heavy sand from gold placers south of Crowders Mountain, Gaston County, was reported to contain monazite (Genth, 1891, p. 77–78, 86), but apparently it is not present in great abundance. The source is unknown. Most of the rocks are fine-grained low-grade schists which were sampled at a number of places and found to be free of monazite (W. R. Griffitts, oral commun., 1952; D. B. Potter, oral commun., 1953). It is remotely possible that this monazite has been carried down from former higher level surfaces of erosion where it had been deposited by streams that reached 10 miles or so into the western monazite belt. More likely this monazite was derived from as yet unrecognized monazite-bearing rocks exposed at the present level of erosion in the vicinity.

MECKLENBURG COUNTY

Todds Branch in Mecklenburg County was reported by Genth (1862, p. 204; 1891, p. 77–78; Eng. and Mining Jour., 1888, p. 2) to have been the source of one crystal of monazite about one-quarter of an inch long, one-eighth of an inch wide, and a little less than one-eighth of an inch thick. The crystal was yellowish brown, had a specific gravity of 5.203, and seemed to be waterworn and somewhat rounded. It was found in auriferous concentrates associated with garnet, zircon, and diamond.

The Todds Branch occurrence has been frequently mentioned in the literature for both monazite and diamond, but the name of the stream has not been shown on published maps. According to J. L. Stuckey, State Geologist of North Carolina (written commun., 1962), Todds Branch lies a few miles to the northwest of Charlotte and is the easternmost of three small streams between the village of Paw Creek on the west and Toddville on the east. Todds Branch is one of the headwater tributaries to Paw Creek, which enters the Catawba River west of Charlotte.

Rocks in the Todds Branch area are dominantly granite, gabbro, and diorite; pegmatite is present but uncommon. The large size of the monazite crystal most likely indicates that the crystal came from pegmatite. Perhaps it had a local source, but possibly the monazite was brought from the western monazite belt by an ancestral Catawba River when that stream was at an older high erosional level. Detritus left at that level when the Catawba carved its present valley might have been reworked by Todds Branch, and any monazite present in the old alluvium would have been deposited in the new sediment. With presently available data it is not possible to determine the origin of the monazite reported at this locality.

Detrital monazite is present in five magnetite- and epidote-rich concentrates from alluvium in small streams southwest of Newell in Mecklenburg County (Henry Bell, 3d, oral commun., 1963). Transparent pale-yellow to translucent brownish-yellow grains make up 1–5 percent of the concentrate. Many grains are subhedral crystal fragments that are scarcely abraded. The source of the monazite seems to be coarse-grained granite that underlies the drainage basins, but the granite has not been sampled for monazite.

ROWAN COUNTY AND DAVIDSON COUNTY

Fifty-seven concentrates from alluvium in the upper reaches of small streams tributary to the Yadkin River in the High Rock quadrangle in Rowan County and Davidson County, were found by White and Stromquist (1961) to contain heavy minerals not present in the low-grade metamorphic rocks drained by the streams. The rocks consist of argillite, weakly metamorphosed tuff and flows of rhyolitic to andesitic composition, and intrusive diabase and gabbro. Nowhere in the area of the quadrangle do the rocks exceed the greenschist facies. Index minerals of amphibolite facies, including staurolite, kyanite, almandine, and sillimanite, are in the concentrates. Monazite is present in 13 concentrates, and zircon in 35. Neither of these minerals has been observed in the rocks in the quadrangle.

The source of the monazite, zircon, and other anomalous minerals was interpreted by White and Stromquist to be rocks of the middle and upper amphibolite facies exposed 30 miles or more to the northwest, particularly in the vicinity of Stokes County and Surry County. It is thought that after erosion from appropriate gneiss, schist, and granite the anomalous heavy minerals, including monazite, were transported southeastward by an ancestral Yadkin River and deposited in alluvium along former courses of the stream. Relicts of this high-level alluvium reached by the small streams that were sampled add the anomalous heavy minerals to the concentrate. There is no local source for the detrital monazite.

CRYSTALLINE ROCKS IN THE EASTERN MONAZITE BELT IN THE PIEDMONT PROVINCE

Monazite was discovered by Mertie in 1949 as an accessory mineral in granite in the eastern part of the Piedmont province about 1¼ miles southeast of Rolesville, Wake County, some 15 miles northeast of Raleigh, N.C. (Mertie, 1953, p. 15, 18, pl. 1). From Rolesville the monazite-bearing rocks were traced north-northeastward for 200 miles to the vicinity of Fredericksburg, Va., and to this heretofore unknown zone Mertie assigned the term "eastern monazite belt."

Rocks in the North Carolina segment of the eastern monazite belt were the source for nine monazite-bearing concentrates in addition to the discovery sample (Mertie, 1953, p. 18–19). Elsewhere in Wake County, monazite occurs as an accessory in granite exposed 1.1 miles southwest of Garner and in granite at two localities near Milburnie on the Neuse River east of Raleigh. Monazite is present in granite exposed at three localities southwest of Louisburg in Franklin County. Granite cropping out 3.6 miles southeast of Norlina and 8 miles southwest of Warrenton in Warren County contains accessory monazite.

The monazite localities in the area between Raleigh and Louisburg are along the western and central part of a north-northeasterly elongate mass of quartz monzonite (Parker and Broadhurst, 1959, p. 1–5). Flanking the pluton on its west side is a thick sequence of regionally metamorphosed sedimentary rocks. These rocks are at the kyanite-staurolite subfacies. The metamorphic grade decreases progressively toward the west and reaches the lowest subfacies of the greenschist facies at a point about 12 miles west of the pluton. These metasedimentary rocks were said by Parker and Broadhurst (1959, p. 5, 13–14) to grade eastward into the quartz monzonite, which they regard as possibly the culmination of the metamorphic changes affecting the sedimentary rocks. It is along this zone of possible metamorphic culmination that the monazite occurs.

This monazite has not been analyzed; thus, whether it contains moderate amounts of thorium oxide, as would be expected if it formed at the kyanite-staurolite grade, is unknown.

STREAM DEPOSITS IN THE PIEDMONT PROVINCE

The history of the discovery and mining of detrital monazite in the Piedmont physiographic province of North Carolina was reviewed in the introductory section on North Carolina. In this section on stream deposits, emphasis is placed on descriptions of specific localities, analytical data on placer monazite, and estimates of tenors and reserves of fluviatile deposits. Data on the placers are summarized in geographic order similar to that followed for the discussion of monazite in crystalline rocks in the Piedmont. The close relation between the kind of source rock and the tenor and composition of detrital monazite, pointed out in the section on "Hypotheses of origin," is given further emphasis.

The known placer deposits in the Piedmont of North Carolina are restricted to the area of the western monazite belt as defined by Mertie (1953, pl. 1). They are in locally derived fluvial sediments that cover the floors of shallow, narrow valleys occupied by perennial streams and underlain by weathered crystalline rocks (Sterrett, 1908b, p. 279–281; Overstreet, Theobald, and Whitlow, 1959, p. 709–713). The fluvial sediments are well bedded, poorly graded, and unconsolidated. Throughout the monazite belt they have much the same stratigraphic succession: at the base is quartz-pebble gravel with a matrix of sandy clay; overlying the basal gravel, or resting on weathered bedrock where gravel is absent, is dense gray clay through which are scattered quartz pebbles and fragments of carbonized wood. Locally the clay is very carbonaceous and grades into peat or muck. Generally above the clay is gray, buff, or brown coarse to fine sand overlain by buff, brown, or gray clayey silt. The uppermost sediment is red to brown sandy silt. It is the most widespread of the flood-plain sediments. At places the red to brown sandy silt rests directly on the dense gray clay, and where it does the top surface of the clay may be channelled, scoured, and pitted. The sequence of fluvial sediments averages 14.6 feet in thickness and is composed of 1.5 feet of gravel, 3.6 feet of clay, and 9.5 feet of sand and silt. The sediments are Recent in age, but small areas of pre-Wisconsin muck, clay, and gravel are present in the heads of some streams. Red to brown sandy silt in the upper part of the sequence has been deposited since the region was cleared for farming in the nineteenth century.

Flood plains in the western Piedmont are rarely more than 2 or 3 miles long or more than 2,500 feet wide (Overstreet, Theobald, and Whitlow, 1959, p. 712). They range in area from several thousand to 7 million square yards. About half of the flood plains are 200–800 feet wide and more than 1 million square yards in area. Small flood plains at the extreme heads of the creeks, which were the sites of former placer mining, are about a few hundred to 200,000 square yards in area, and the smallest of these contain but a few hundred to a few thousand cubic yards of monazite-bearing sediment. The average volume of sediment in individual downstream flood plains is 7 million cubic yards, and the largest continuous monazite-bearing flood plain in North Carolina, along the South Fork Catawba River in Catawba County and Lincoln County, contains about 60 million cubic yards of sediment.

Tenors of the fluvial deposits range from less than 0.1 pound of monazite per cubic yard to more than 50 pounds per cubic yard and average about 0.8 pound per cubic yard. In 84 flood plains classed as placers in the Piedmont of North and South Carolina the average tenor in monazite for the sequence of sediments was estimated to be 1.3 pounds per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 712). The greatest tenors are in coarse-grained basal gravel, and the least tenors are in silt and clay. Tenors decrease downstream from large values at the heads of creeks and branches to small values in the lower reaches of large tributaries in the monazite belt or parts of trunk streams in and immediately downstream from the belt. Gravel such as that mined in the heads of creeks was reported by Mertie (1953, p. 10) to average 8.4 pounds of monazite per cubic yard at 52 localities sampled in North and South Carolina. The average tenor of headwater sediments taken from grass roots to bedrock at many hundreds of localities in these two States was estimated by Overstreet, Theobald, and Whitlow (1959, p. 714) to be about 4 pounds of monazite per cubic yard. Extreme examples of local concentration mentioned in the literature show that mined gravel can contain as much as 30 percent of monazite (Graton, 1906, p. 117), but mostly the gravel contains less than 1 percent of monazite, generally 0.25 percent or less (Nitze, 1897, p. 129; Böhm, 1906; Ladoo, 1925, p. 396; McDaniel, 1943, unnumbered p.; Houk, 1946, p. 8).

The resources in monazite in fluviatile placers along tributaries to the Broad River and southern tributaries to the Catawba River in Cleveland, Rutherford, Polk, McDowell, Burke, Catawba, and Lincoln Counties, N.C., were estimated in 1959 to be at least 490,000 short tons (Overstreet, Theobald, and Whitlow, 1959, p. 713). Resources of monazite in placers in the western monazite belt to the northeast of the Catawba River and southwest of the Yadkin River, N.C., have not been evaluated, but they are probably on the order of one-third as large as the resources southwest of the Catawba River. An appraisal of the area between the Yadkin River and the North Carolina State line at Virginia indicates significant resources of monazite are not present (A. M. White, written commun., 1954). No appraisal of monazite resources in fluviatile placers in the eastern monazite belt of Mertie (1953, pl. 1) has been made. The writer thinks that fluviatile placers in the eastern belt will prove to have a lower average tenor than stream placers in the western belt. Possibly the average amount of thorium oxide in detrital monazite in the eastern belt is less than in the western belt. Significant deposits of detrital monazite may not exist in the Piedmont between the two belts. This estimate should be strongly qualified by pointing out the possibility of placers associated with local masses of monazite-bearing granite like the one found by Henry Bell, 3d (oral commun., 1963) in eastern Mecklenburg County or by pointing out the possibility of fossil or modern placers related to relicts of alluvium left along former drainage ways (White and Stromquist, 1961).

STOKES COUNTY AND SURRY COUNTY

Streams tributary to the Dan and Yadkin Rivers in parts of Stokes and Surry Counties, N.C., in the western monazite belt of Mertie (1953, pl. 1) were investigated in 1952 for possible deposits of detrital monazite by A. M. White and G. A. Miller of the U.S. Geological Survey (A. M. White, written commun., 1954). Small amounts of monazite were observed at several localities, but placers suitable for mining were not found.

The area is underlain by staurolite- and epidote-bearing mica schists intruded locally by granite. Pegmatite is not as widespread in these schists as it is in the sillimanitic core of the belt exposed to the southwest of the Yadkin River (Overstreet and Griffitts, 1955, pl. 1), and migmatitic rocks are absent. Out of 126 concentrates from sediments in streams draining an area of 600 square miles in the two counties, only 17 contained more than a trace of monazite. Ilmenite was the most abundant mineral in most of the concentrates, and variable amounts of staurolite, epidote, magnetite, and garnet were present. The mineralogical composition of the 17 concentrates with more than a trace of monazite is shown in table 69. Out of 15 concentrates, 5 are from Faggs Creek, North Double Creek, Big Creek, and other tributaries to the Dan River in Stokes County, and 12 out of 111 concentrates are from tributaries to the Ararat River, Fisher River, and Mitchell River in Surry County. Estimates indicated only two localities where the tenor of the sediments exceeded 1 pound of monazite per cubic yard. The maximum estimated tenor was 1.8 pounds of monazite per cubic yard found for riffle gravel in Faggs Creek at a point about 3 miles northwest of Danbury, Stokes County (table 70).

Even if the tenors of the sediments had been considerably greater, the streams are not well suited for monazite mining. Flood plains in the sampled parts of Stokes County and Surry County are small and discontinuous. In general the best-developed flood plains tend to be along the upstream parts of the large creeks, but the alluvium is shallow, averaging only 10.5 feet in thickness except on the main rivers where the average thickness reaches about 21 feet. The large flood plains are outside the areas of monazite-bearing bedrock, and their sediments contain no monazite or only a trace. No flood plain in this area is a monazite placer.

WILKES, IREDELL, ALEXANDER, CALDWELL, AND CATAWBA COUNTIES

Late in the history of monazite placer mining in North Carolina, about 1906, monazite was discovered by D. B. Sterrett in Cub Creek near Wilkesboro in Wilkes County (Pratt, 1907b, p. 109; Pratt and Sterrett, 1908a, p. 315; Bryson, 1937, p. 131). At the time it was found the occurrence was described as having only a limited extent, and the percentage of monazite in the concentrates was said to be small; nevertheless, the locality is the northeasternmost placer discovered during the life of the monazite industry in the Carolinas. Placers in Wilkes County have received no further attention.

The year 1906 also saw the extension of known placer deposits into northern Iredell County. Some monazite was even produced in the county during that year and also from 1915 through 1917, but available records do not identify the mining district except to say that it was north of Statesville (Pratt, 1907b, p.

TABLE 69.—*Mineralogical composition, in weight percent, of monazite-bearing concentrates from alluvium in Stokes and Surry Counties, N.C.*

[Analysts: Jerome Stone, M. N. Girhard, H. B. Groom, Jr., C. J. Spengler, and R. P. Marquis, U.S. Geol. Survey, in 1953. Symbols used: Tr., trace, --, absent]

	110268	110230	110231	110224	110223	110220	110218	110219	110216	110213	110214	110211	110210	110208	98805	98806	98780
Weight of concentrate..grams..	115.7	77.9	39.0	49.7	87.3	26.0	54.6	71.8	20.6	112.4	104.0	144.2	26.3	25.0	49.0	19.5	22.8
Magnetite	6	4	16	3	3	3	18	5	3	3	5	2	3	3	1	Tr.	7
Ilmenite	60	60	52	78	83	60	71	68	73	85	72	72	81	64	45	88	39
Quartz	13	5	15	5	7	16	7	5	15	4	10	13	5	21	15	8	24
Monazite	8	2	2	11	4	12	2	2	1	1	2	2	1	4	4	3	1
Garnet	11	9	6	1	2	2	Tr.	3	4	2	6	5	7	1	--	--	Tr.
Zircon	Tr.	2	3	Tr.	Tr.	1	2	Tr.	2	1	2	Tr.	Tr.	1	--	Tr.	1
Sillimanite	--	2	Tr.	--	--	--	--	2	Tr.	Tr.	Tr.	Tr.	Tr.	--	--	--	3
Staurolite	--	4	Tr.	1	Tr.	6	Tr.	14	1	3	Tr.	6	3	4	35	--	2
Amphibole	1	1	Tr.	Tr.	Tr.	--	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	--	--	--	--	2
Tourmaline	Tr.	Tr.	--	Tr.	--	Tr.	Tr.	1	Tr.	Tr.	--	Tr.	--	1	--	--	--
Epidote	--	9	6	1	1	Tr.	Tr.	Tr.	Tr.	1	1	--	Tr.	1	Tr.	1	21
Other minerals	[1] 1	[1] 2	[1] Tr.	[2] Tr.	[3] Tr.	--	--	[1] Tr.	[3] Tr.	--	[1] 2	--	--	--	--	--	--

[1] Rutile.
Stokes County:
110268. Faggs Creek.
110230, 110231. North Double Creek.
110224, 110223. Big Creek.

[2] Xenotime.
Surry County:
110218, 110219,
110216, 110220. Big Creek.
110213, 110214. Toms Creek.
110211, 110210. Flat Shoal Creek.

[3] Kyanite.
Surry County—Continued
110208. Stoney Creek.
98805, 98806. Stewarts Creek.
98780. Fisher River.

TABLE 70.—*Estimated tenor, in pounds per cubic yard, of monazite-bearing sediments in Stokes and Surry Counties, N.C.*

[A. M. White (written commun., 1954)]

	Stokes County						Surry County										
	Faggs Creek	North Double Creek		Big Creek			Toms Creek					Flat Shoal Creek		Stony Creek	Stewarts Creek		Fisher River
	110268	110230	110231	110224	110223	110220	110218	110219	110216	110213	110214	110211	110210	110208	98805	98806	98780
Monazite	1.8	0.3	0.2	1.1	0.7	0.6	0.2	0.3	0.04	0.2	0.4	0.6	0.04	0.2	0.4	0.1	0.05
Ilmenite	13.9	9.3	4.0	7.7	14.5	3.1	7.7	9.7	3.0	19.1	14.9	20.7	4.3	3.2	4.4	3.4	1.8
Zircon	--	.3	.2	--	--	.05	.2	--	.08	.2	.4	--	--	.05	--	--	.05
Garnet	2.5	1.4	.5	.1	.3	.1	--	.4	.2	.4	1.2	1.4	.4	.05	--	--	--
Other minerals	(1)	(2)	--	--	--	--	--	(3)	(4)	--	(5)	--	--	--	--	--	(6)

[1] Rutile, 0.2.
[2] Rutile, 0.3; sillimanite, 0.3.
[3] Sillimanite, 0.3.
[4] Kyanite, 0.04.
[5] Rutile, 0.4.
[6] Sillimanite, 0.1.

109, 122; Sterrett, 1908b, p. 274; Pratt and Berry, 1919, p. 104–105; Drane and Stuckey, 1925, p. 19; Bryson, 1927, p. 15–16). Pratt's map of 1916 indicates the placers could have been anywhere in the northwestern part of Iredell County to the north, northwest, and northeast of Statesville (Pratt, 1916, pl. 1).

As early as 1880 monazite was known in veins, schist, and gold placers at Milhollands Mill on Third Creek about 2.6 miles S. 30° E. from Hiddenite in Alexander County (Genth and Kerr, 1881, p. 84, 91; Dana, E. S., 1882, p. 247; Rath, 1886, p. 149–150; Eng. and Mining Jour., 1888, p. 2; Genth, 1891, p. 77–78, 86; Mertie, 1953, p. 8), but the placers seem not to have attracted commercial attention until about 1906. In 1907 the county was listed as one of the monazite-producing areas in North Carolina (Pratt, 1908, p. 61). The locations of the mined monazite placers have not been given in the literature. Most of the county is within the monazite-bearing area outlined by Pratt (1916, pl. 1), but the common references to monazite in the region around Hiddenite and Stony Point suggest that the eastern part of the county may have been the main source. Detrital monazite from Third Creek at the original site of Milhollands Mill was said by Mertie (1953, p. 12) to contain 5.19 percent of ThO_2 and 0.36 percent of U_3O_8.

Monazite placers were discovered in Caldwell County between 1893 and 1908, but they do not seem to have been mined and details as to location have not been published (Pratt, 1907b, p. 109; Sterrett, 1908b, p. 274). Probably the placers are in the eastern and southeastern parts of the county.

Catawba County was known as early as 1893 to possess monazite placers. The western part of the county and the drainage basins of Henry Fork and Jacob Fork were the most often cited localities in the early literature (Mezger, 1895, p. 822; Nitze, 1895c; Pratt, 1903, p. 181; Böhm, 1906; Pratt, 1907b, p. 109; Sterrett, 1908b, p. 274). Other than to indicate these general areas and to show that monazite was shipped from the county during 1906 and 1907, the early reports contribute little to a knowledge of monazite in the county. During 1952 A. M. White of the U.S. Geological Survey studied the distribution of detrital monazite throughout the county. Results of his investigations showed that monazite is present in the western and eastern parts of the county and locally in the central part, that rutile, sillimanite, and almandine commonly accompany detrital monazite in western Catawba County but not in the central and eastern areas, and that four main drainage basins contain monazite (Overstreet and Griffitts, 1955, pl. 1; Overstreet, Cuppels, and White, 1956; Overstreet, Theobald, and Whitlow, 1959; Overstreet, 1962, figs. 1, 2).

The southeast edge of the core of the monazite belt passes northeastward across the western part of Catawba County (A. M. White, written commun., 1954). In this area, which is about 8–12 miles wide, monazite makes up 5–20 percent of the heavy minerals in concentrates from alluvium. The flank of the monazite belt is very narrow adjacent to the core in the southwestern part of the county, but about 4 miles north of Newton a great eastward expansion occurs, and a zone in which concentrates from stream sediments have 1–5 percent of monazite extends eastward to the Catawba River and thence southward across Catawba County and Lincoln County (Overstreet, 1962, fig. 2). A small outlying area of monazite-bearing alluvium occurs at Newton and extends southeastward nearly to the border with Lincoln County.

Rutile and sillimanite are minor accessory minerals, and garnet and ilmenite are major accessory minerals in monazite-bearing concentrates from the southwestern part of the county and the outlying area at and southeast of Newton. The occurrences are in parts of broad and persistent bands of these minerals which are found in the core of the monazite belt from the Catawba River southwestward into South Carolina. Small amounts of rutile and garnet are present in monazite-bearing concentrates from the flank of the belt in the eastern part of the county, and ilmenite is common there, but sillimanite is only sporadically present.

Concentrates from eastern Catawba County are rich in epidote and staurolite, and staurolite is locally present at the extreme edge of the core of the belt in the southwest corner of the county.

Magnetite is generally absent from concentrates from the core of the belt in the western part of the county, but it makes up as much as 40 percent of some concentrates from the monazite-bearing area at and southeast of Newton. Magnetite in abundances up to 20 percent of the concentrate is present in eastern Catawba County on the flank of the monazite belt. It becomes increasingly abundant southward into Lincoln County.

The main monazite-bearing streams in Catawba County are Lyle Creek, Clark Creek, the downstream part of Henry Fork, and Jacob Fork. Their combined resources in detrital monazite were estimated by White to be about 49,000 short tons (Overstreet, Theobald, and Whitlow, 1959, p. 711).

Lyle Creek and adjacent streams are tributary to the Catawba River in northeastern Catawba County. Their basins are underlain by deeply weathered biotite schist, biotite gneiss, sillimanite schist, and hornblende gneiss, all of which are more or less injected by pegmatite (A. M. White, written commun., 1954). Staurolite-bearing rocks are prominent east and south of the mouth of Lyle Creek but are scarce in the basin. Lyle Creek and adjacent streams are on the southeast flank of the monazite belt.

Flood plains along the downstream half of Lyle Creek are discontinuous and wide compared to their lengths, and they attain widths as great as 2,200 feet. Along the upstream half of Lyle Creek the flood plains were reported to average about 400 feet in width (A. M. White, written commun., 1954). Sand and silt was estimated by White to make up about 75 percent of the sediment, clay about 16 percent, and gravel 9 percent. Because of the large proportion of fine-grained sediment in the flood plains and the location of Lyle Creek and adjacent streams on the flank of the monazite belt, the average tenor of the flood-plain sediments was estimated by White to be only 0.4 pound of monazite per cubic yard and the resources some 11,300 short tons of monazite (Overstreet, Theobald, and Whitlow, 1959, p. 711).

Clark Creek and other tributaries to the South Fork Catawba River drain the area of monazite-bearing rocks in central Catawba County from the vicinity of Newton southeastward nearly to Lincoln County. Clark Creek flows southward out of these monazite-bearing rocks into a monazite-free part of central Lincoln County and empties into the South Fork Catawba River on the west side of Lincolnton (Overstreet, 1962, fig. 1). Streams in only about half of the drainage basin contain monazite-bearing alluvium. Resources in monazite for the basin were estimated by A. M. White to be about 11,000 short tons in alluvium, the average tenor being 0.4 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711).

The downstream part of Henry Fork is the stretch of river between Queens Creek in Burke County and the confluence of Henry Fork with Jacob Fork in Catawba County. The junction of the two rivers forms the South Fork Catawba River. Biotite gneiss, biotite schist, and sillimanite schist are the prinicpal kinds of rocks in the downstream part of Henry Fork. Pegmatite is locally abundant (A. M. White, written commun., 1954). This part of the basin of Henry Fork is in the center and on the southeast side of the core of the monazite belt. Concentrates from alluvium near the head of Queens Creek contain from 40 to 50 percent of monazite. This percentage declines eastward to the border between Burke County and Catawba County where concentrates contain 20 percent of monazite. From this point to the confluence of Henry Fork and Jacob Fork, concentrates contain from 10 to 20 percent of monazite. Rutile is absent from Queens Creek to the Catawba County line but is present in concentrates from this boundary to the mouth of Henry Fork. Sillimanite makes up from 1 to 5 percent of the concentrate, and garnet constitutes from 5 to 20 percent of the heavy-mineral suite. Ilmenite is common. Epidote and staurolite are virtually absent. Magnetite is absent or scarce through the western part of the basin but appears toward the east and makes up 1–30 percent of the concentrate. Magnetite reaches its greatest abundance in alluvium from creeks near the confluence of Henry Fork and Jacob Fork at the flank of the belt.

Flood-plain sediments range in thickness from about 7 feet along small creeks to about 18 feet in parts of the valley of Henry Fork, but only about 10 percent of the sediment is gravel. The average tenor of the sediments was estimated by A. M. White to be 1.0 pound of monazite per cubic yard, and the resources in monazite were estimated to be at least 13,700 short tons (Overstreet, Theobald, and Whitlow, 1959, p. 711).

Some tributaries to Henry Fork in Burke County were formerly mined for monazite, but specific localities have not been given in the literature (Nitze, 1895c; Pratt, 1903, p. 181; Böhm, 1906).

Jacob Fork drains parts of Burke, Catawba, Cleveland, and Lincoln Counties immediately south of the basin of Henry Fork. Jacob Fork rises in the South Mountains in Burke County and flows eastward across biotite schist, biotite gneiss, and sillimanite schist at the core of the monazite belt to its junction with Henry Fork in Catawba County on the southeast flank of the belt. Parts of the stream and its tributaries in Burke, Catawba, and Lincoln Counties were said to have been mined for monazite, but individual placer deposits were not described (Nitze, 1895c; Pratt, 1903, p. 181; Böhm, 1906).

Concentrates from alluvium at the headwaters and mouth of Jacob Fork were found by A. M. White (written commun., 1954) to have only a few percent of monazite, but concentrates from streams in the central part of the basin were found to contain 30–60 percent of monazite. Gravel from streams in the basin was estimated by White to contain as much as 16.9 pounds of monazite per cubic yard, but most samples of gravel had less than 5 pounds of monazite per cubic yard:

	Tenor of gravel (lb per cu ft)
Monazite	0.08–16.9
Ilmenite	.6 –38.8
Rutile	0 – 1.1
Zircon	0 – 2.1
Garnet	.1 – 8.5
Kyanite	0 – .7
Sillimanite	0 – 1.4

The tenor of gravel in a probable former placer along Camp Creek, a southern tributary to Jacob Fork in Cleveland County and southeastern Burke County, was estimated by Mertie (1953, p. 8, 10) to be 7.1 pounds of monazite per cubic yard. Analysis of this monazite disclosed 6.20 percent of ThO_2 and 0.45 percent of U_3O_8 (Mertie, 1953, p. 12).

Rutile in low percentages occurs in about half of the concentrates from the basin of Jacob Fork. Sillimanite, commonly present in amounts of as much as 5 percent of the concentrate, locally reaches 10 percent. In the northwestern part of the basin it is absent. Most concentrates contain 15–20 percent of garnet and 50–70 percent of ilmenite. Staurolite is common in concentrates from streams entering Jacob Fork from the line between Burke County and Catawba County to a point about 6 miles upstream from Henry Fork, but epidote is virtually absent. Magnetite is common in concentrates from the lower end of Jacob Fork (Overstreet and Griffitts, 1955, pl. 1).

Resources in monazite in the basin of Jacob Fork were estimated by A. M. White to be about 13,200 short tons in alluvim, the average tenor being 0.8 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711).

BURKE COUNTY AND MCDOWELL COUNTY

Detrital monazite was reported from gold placers in Burke County and McDowell County in 1871 by F. A. Genth. W. E. Hidden found it to be a common accessory mineral in concentrates from placers in these counties, and in 1880 he shipped 50 pounds of detrital monazite from the Brindletown gold placer district on Silver Creek in Burke County (Genth and Kerr, 1881, p. 84). Systematic recovery of placer monazite in Burke County was not undertaken until 6 years later, although monazite concentrates from the county were described (Mallet, 1882, p. 205; Dana, E. S., 1882, p. 248; Penfield, 1882, p. 251; Am. Naturalist, 1883, p. 313; Dana, E. S., 1884, p. 542). In 1887 the Brindletown district was the source of the first real output of monazite, 12 short tons, produced in North Carolina, and thereafter production was maintained through 1910 with sporadic mining through 1917 (table 30). It is not known when placers were first opened for monazite in McDowell County, but it was probably almost at the same time sustained production began in Burke County, because as early as 1888 deposits in McDowell County were said to have exploitable monazite sand (Eng. and Mining Jour., 1888, p. 2). Mining apparently began in McDowell County around Dysortville and Demming in the headwaters of Muddy Creek in the next drainage basin to the west of the Silver Creek basin (Dennis, 1898, p. 494; Pratt, 1901, p. 31; Zodac, 1958). In 1898 an act was passed by the Legislature of North Carolina to prohibit mining in Muddy Creek (Pratt, 1901, p. 31). Between that date and 1900 monazite was not mined in the county, but from 1901 through 1906 McDowell County was again a source of monazite (table 58), but the mining localities are not known. In 1902 tributaries to Muddy Creek known as Long Branch, Alexander Branch, and MacLawrath Branch were cited as sources of placer monazite (Pratt, 1902, p. 60), but it is not clear whether these creeks were mined before or after the act of 1898. The total output of placer monazite in Burke County and McDowell County is not known, but it may have been as much as one-third of the total production in North Carolina.

Monazite-bearing concentrates from gold placers at the heads of Silver Creek and Muddy Creek between Brindletown in Burke County and Dysortville in McDowell County were commonly cited as sources for rare minerals in North Carolina (Genth, 1891, p. 77–78, 86; Pardee and Park, 1948, p. 65). In 1895 the number of minerals identified in concentrates from gold sands near Brindletown was said to be immense (Becker, 1895, p. 291), and in 1896 a list was published showing 103 varieties of minerals in placers at Dysortville (Eng. and Mining Jour., 1896).

After the monazite industry closed in North Carolina in 1917, the placers in Burke County and McDowell County received no geologic attention until 1943, when W. T. McDaniel of the Tennessee Valley Authority examined several deposits in Burke County (McDaniel, 1943; Lefforge and others, 1944), and 1945, when J. B. Mertie, Jr., of the U.S. Geological Survey sampled placers in both counties (Mertie, 1953, p. 8–12). Systematic study of the placers was not undertaken until 1952, when A. M. White of the U.S. Geological Survey sampled and drilled monazite-bearing streambeds in Burke County and McDowell County (Overstreet, Cuppels, and White, 1956; Overstreet, Theobald, and Whitlow, 1959).

The results of White's work showed that all streams in Burke County are monazite bearing and that most streams in the eastern part of McDowell County contain monazite (A. M. White, written commun., 1954). Burke County from a point 4 miles east of Morganton is in the core of the monazite belt. Concentrates from alluvium in this area contain from 10 to 30 percent of monazite and locally contain as much as 60 percent (the previously described Jacob Fork area in southeastern Burke County). The western part of Burke County and eastern McDowell County nearly as far west as Marion are in the northwest flank of the monazite belt. Most concentrates from alluvium in this area have 1–5 percent of monazite, and some lack monazite. A zone at the head of South Muddy Creek in McDowell County has alluvium in which concentrates contain 5–20 percent of monazite. This zone extends northeastward into the drainage basin of Silver Creek in Burke County. This rather small zone on the flank of the belt includes most of the famous placer localities in the area around Dysortville and Brindletown (Overstreet, 1962, fig. 2).

Rutile is an uncommon accessory mineral in concentrates except in southeastern and northeastern Burke County. Sillimanite is a nearly constant accessory mineral in amounts between 1 and 5 percent of the concentrate in the core of the belt through Burke County east of Morganton. Locally sillimanite makes up as much as 20 percent of the concentrate in northeastern Burke County. On the flank of the belt, including the monazite-rich area at the heads of South Muddy Creek and Silver Creek, only traces of sillimanite are present. Northwest of the monazite belt in the area around Marion, McDowell County, kyanite is a common component of concentrates. In the monazite-bearing part of McDowell County and throughout Burke County, garnet commonly makes up more than 5 percent of the concentrate. In the core of the belt in Burke County east of Morganton, garnet usually is present in amounts between 15 and 40 percent of the concentrate, but on the flank of the belt it seldom exceeds 10 percent of the concentrate. Ilmenite is much more abundant in the core of the monazite belt in the eastern part of Burke County than on the northwest flank of the belt in the western part of Burke County and the eastern part of McDowell County. Commonly concentrates contain 50–70 percent of ilmenite in the core and 10–30 percent on the flank of the belt. Concentrates from the northwest flank of the belt are likely to have 1–25 percent of epidote and 5–70 percent of magnetite, whereas those from the core of the belt in Burke County contain no epidote and less than 5 percent of magnetite. Many concentrates are free of magnetite (Overstreet and Griffitts, 1955, p. 556).

The resources in monazite in Burke County were appraised by A. M. White in five clusters of streams of which two, the downstream part of Henry Fork and the basin of Jacob Fork, extend into Catawba County and were reviewed in the section "Wilkes, Iredell, Alexander, Caldwell, and Catawba Counties." The three other clusters of streams are Hunting Creek and six short tributaries to the Catawba River, Laurel Creek and other headwater tributaries to Henry Fork, and Silver Creek. Monazite-bearing streams in McDowell County include north-flowing creeks which enter the Catawba River and south-flowing streams which are tributary to the Second Broad River. Only those streams emptying into the Catawba River are discussed here, because the south-flowing Second Broad River drainage is more appropriately described in the section on Rutherford County, which follows. Muddy Creek discharges into the Catawba River and drains most of the monazite-bearing parts of McDowell County. Resources in the three streams in Burke County and the Muddy Creek basin in McDowell County were estimated by A. M. White to be at least 43,000 short tons of monazite (Overstreet, Theobald, and Whitlow, 1959, p. 711).

Hunting Creek and six other small streams rise in the South Mountains and flow northward into the Catawba River between Morganton in Burke County and the Burke-Catawba County line to the east. The westernmost of these small streams, Hunting Creek, is on the northwest flank of the monazite belt, but the other streams are in the core of the belt (A. M. White, written commun., 1954). From west to east the percentage of monazite increases in concentrates from alluvium. Concentrates from Hunting Creek commonly have from 1 to 5 percent of monazite; in the extreme southeast branches of Hunting Creek, concentrates have as much as 20 percent of monazite. From 5 to 10 percent of monazite is in concentrates from Double Creek, the next stream to the east, and eastward in McGalliard Creek the abundance rises to 20 percent or more. In the most easterly part of the area, around Drowning Creek, the concentrates contain as much as 30 percent of monazite.

Flood plains on these streams are small and discontinuous; only Hunting Creek has flood plains along most of its length. Most of the flood-plain sediments are about 8–12 feet thick. The weighted-average tenor of the sediments was estimated by White to be 0.7 pound of monazite per cubic yard, and the resources were estimated to be about 5,600 short tons of monazite (Overstreet, Theobald, and Whitlow, 1959, p. 711). Despite the low average tenor of the alluvium, most of the monazite is along Hunting Creek because it has about 75 percent of the total volume of alluvium in the area (A. M. White, written commun., 1954):

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Hunting Creek	0.7	3,500
Double Creek	.8	160
Hoyle Creek	.9	470
Island Creek	1.6	70
Drowning Creek	2.3	750
Others	--------	650
Total	--------	5,600

Laurel Creek and other headwater tributaries to Henry Fork in Burke County were estimated by A. M. White to contain about 2,300 short tons of monazite in alluvium with an average tenor of 0.6 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711). The area drained by these streams is underlain by biotite gneiss, biotite schist, and sillimanite schist in a monazite-poor reentrant of the flank of the belt on the northwest side of the core. Flood plains are small and discontinuous. Despite local high-tenor gravel in riffles along small streams, the tenor and resources of individual streams are small. A representative sample containing 7 pounds of monazite per subic yard was panned by Mertie (1953, p. 8, 10) from Rock Creek at a locality seven-eighths of a mile east-northeast of Pleasant Grove Church. According to A. M. White (written commun., 1954) flood-plain sediments in Rock Creek contain the highest average tenor:

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Headwaters of Henry Fork	Trace	Trace
Henry Fork near Enola	0.9	550
Henry Fork from Dafty Creek to Ben Branch	.4	500
Rock Creek	1.7	380
Laurel Creek	.3	18
Henry Fork between Laurel Creek and Cub Creek	.9	850
Total	--------	2,298

Detrital monazite from Rock Creek was reported by Mertie (1953, p. 12) to contain 4.94 percent of ThO_2 and 0.58 percent of U_3O_8.

Silver Creek rises in the South Mountains in the southwestern part of Burke County and flows toward the north and northeast to empty into the Catawba River about a mile west of Morganton. The basin of Silver Creek is underlain by biotite schist, biotite gneiss, hornblende gneiss, granitic rocks, and sparse sillimanite schist on the northwest flank of the monazite belt (A. M. White, written commun., 1954). Concentrates from alluvium in the easternmost branches of the creek and in the downstream parts of the other branches generally contain 5 percent of monazite or less, but in the upper reaches of the western branches, particularly in the Brindletown area, concentrates commonly contain 20 percent of monazite. Even in the lower parts of the stream, local fairly rich occurrences of monazite can be found in riffle gravel along small tributaries. A sample of riffle gravel from a locality 2.5 miles south of Glen Alpine was reported by Mertie (1953, p. 8, 10) to contain 4 pounds of monazite per cubic yard.

As was previously stated, detrital monazite has long been known in the Silver Creek basin, and gold placers in the Brindletown area were the earliest commercial source for monazite in the United States. The Mills mine (Genth and Kerr, 1881, p. 84), the White Bank gold mine on the lower slope of Pilot Mountain west of Brindle Creek, Hall Creek, and the Linebacher place (Pratt, 1902, p. 60) were frequently mentioned as having been mined for monazite. The placers are regarded as having been mined out for gold by 1905 (Pardee and Park, 1948, pl. 14).

Possibly the reason the head of Silver Creek in the Brindletown area was better known as a monazite placer area than downstream parts of the basin is because concentrates from the Brindletown area contain less magnetite and epidote than concentrates from other parts of the basin. Magnetite reaches 70 or 80 percent of the concentrate locally in tributaries to Silver Creek below the mouth of Hall Creek and in parts of eastern tributaries like Double Branch (A. M. White, written commun., 1954). Concentrates from Hall Creek and the headwaters of Bailey Fork are relatively free from epidote, but concentrates from the rest of the basin contain as much as 30 percent of epidote.

Flood plains are commonly long and continuous on Silver Creek and its tributaries, and this pattern is maintained far up toward the headwaters of the north-flowing tributaries. Short reaches along the central part of Silver Creek, Clear Creek, and Bailey Fork lack flood plains. The widest flood plains begin near the mouth of Clear Creek and extend downstream along Silver Creek to a point about a mile upstream from the Catawba River. In this part of the valley the sediments are 17–21 feet thick, and near the head of Hall Creek they are 12 feet thick. Gravel decreases in abundance downstream from 25 to 40 percent of the sediment near the heads of the streams to 5–10 percent near the mouth of Silver Creek.

An appraisal by A. M. White of the resources of monazite in the basin of Silver Creek revealed at least 16,500 short tons of monazite in alluvium that has an average tenor of 0.8 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959,

p. 711). These resources were principally in the great flood plain along Clear Creek and Silver Creek downstream from the mouth of Clear Creek (A. M. White, written commun., 1954):

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Brindle Creek, Silver Creek, and Hall Creek to mouth of Hall Creek	0. 7	1, 800
Silver Creek between Hall Creek and Clear Creek	. 6	2, 250
Sutterwhite Creek, upper part of Clear Creek, and Double Branch	1. 7	3, 150
Lower part of Clear Creek, Silver Creek to a point 1.25 miles upstream from Bailey Fork	1. 0	6, 000
Silver Creek from point 1.25 miles upstream from Bailey Fork to Catawba River	. 4	1, 950
Bailey Fork	1. 1	1, 350
Total	--------	16, 500

Two areas in the basin of Silver Creek and one on a nearby part of the Catawba River were explored by the U.S. Bureau of Mines in 1952. During February two churn-drill holes were sunk near the upstream end of the main flood plain on Hall Creek, and one hole was drilled near the mouth of Hall Creek upstream from the Silver Creek valley (R. F. Griffith, written commun., 1952). In October four holes were drilled in the flood plain along Silver Creek at the mouth of Clear Creek, and three holes were sunk in a large flood plain on the Catawba River near Morganton (Hansen and White, 1954, p. 4–5). Results of the drilling on Hall Creek showed that the alluvium is 8–17 feet thick and that it contains 25–38 pounds of black sand per cubic yard, of which 0.84–1.39 pounds per cubic yard is monazite, and a little gold.

Results of drilling in the valley of Silver Creek at the mouth of Clear Creek showed that the alluvium contained 12 pounds of black sand having 0.83 pound of monazite and about 4 cents worth of gold per cubic yard. A downstream decrease in the tenor in monazite was indicated. The tenor dropped progressively to 0.6 pound and 0.4 pound per cubic yard at the lower end of Silver Creek (Hansen and White, 1954, p. 5, 22–23). A mineralogical analysis of a composite concentrate from sediment from the four drill holes disclosed 18 percent of epidote and 6.2 percent of monazite (Hansen and White, 1954, p. 15):

	Percent		*Percent*
Epidote	18	Monazite	6. 2
Ilmenite	32	Rutile	2
Quartz	11	Sillimanite and kyanite	4
Garnet	13	Xenotime	. 6
Hornblende	5		
Magnetite	1	Total	98. 8
Zircon	6		

Less than 1 percent each of pyrite, spinel, tourmaline, muscovite, and radioactive opaque minerals were present in the composite concentrate. Reserves in this part of Silver Creek were estimated to be 6,250 short tons of monazite, 38,500 short tons of ilmenite, 15,800 short tons of garnet, and 6,800 short tons of zircon (Hansen and White, 1954, p. 24).

Monazite sand from the Brindletown district was hand picked by Penfield (1882, p. 251–252) to provide a clean separate for analysis. Penfield carefully chose only the large monazite grains having a cinnamon-brown color, thereby practically insuring that the detrital grains he analyzed were derived from pegmatite because the monazite from the schists and gneiss tends to be fine-grained and yellow. This brown monazite was found to have a specific gravity of 5.10 and an average of 6.49 percent of thorium oxide (Penfield, 1882, p. 252; Johnstone, 1914, p. 58; Imp. Inst. [London], 1914a, p. 60).

Chemical analyses, in percent, of monazite from the Brindletown district

	1	2	3	Mean
Ce_2O_3	31. 38	31. 94	30. 77	31. 38
$(La, Di)_2O_3$	30. 67	30. 80	31. 17	30. 88
ThO_2	6. 68	6. 24	6. 56	6. 49
P_2O_5	29. 45	29. 20	29. 20	29. 28
SiO_2	1. 40	--------	--------	1. 40
Loss on ignition	. 20	. 20	--------	. 20
Total	99. 78	98. 38	97. 70	99. 63

The highest grade of monazite sand from the Brindletown area of Silver Creek was said by Nitze (1895c) to contain 4.00–6.60 percent of ThO_2, whereas commercial concentrates from the same area were reported by Pratt (1902, p. 60) to contain 2.18–6.54 percent of ThO_2. Monazite sand from an unknown locality in Burke County was reported to contain 7.28 percent of ThO_2 (Pratt, 1903, p. 182). Schaller (1922, p. 15) stated that monazite from Brindletown was analyzed by W. F. Hillebrand of the U.S. Geological Survey and found to contain 4.3 percent of ThO_2. Detrital monazite from a southern tributary to Silver Creek 2½ miles south of Glen Alpine was reported by Mertie (1953, p. 12) to have 2.48 percent of ThO_2 and 0.28 percent of U_3O_8. Monazite from the Silver Creek flood plain near the mouth of Clear Creek was analyzed by the U.S. Bureau of Mines and shown to have 4.8 percent of ThO_2 and 0.44 percent of U_3O_8 (Hansen and White, 1954, p. 21).

Muddy Creek rises in southeastern McDowell County and flows north to its junction with the Catawba River in Burke County. It has two main forks known as South Muddy Creek and North Muddy Creek which join about 1.4 miles from the Catawba River. The basins of these streams are underlain by biotite gneiss, hornblende gneiss, biotite schist, granite, pegmatite, and scarce sillimanite- and kyanite-bearing schists. Muddy Creek and its tributaries are on the northwest flank of the monazite belt in an area where most concentrates from alluvium contain from 1 to 5 percent of monazite. Tributaries entering the central reaches of North Muddy Creek between Glenwood and Caleb Branch are commonly devoid of monazite. Concentrates contain as much as 10 percent of monazite along North Muddy Creek and Glade Creek to the northwest of Glenwood, along the middle part of Shadrick Creek, along South Muddy Creek near the mouth of Southeast Muddy Creek, and upstream along Southeast Muddy Creek. Concentrates having 20 percent of monazite come mainly from the Dysortville area on Southeast Muddy Creek and from South Muddy Creek at the mouth of Long Branch.

Most concentrates from alluvium in the basin of South Muddy Creek have less than 40 percent of ilmenite, and concentrates from western headwater tributaries in the Demming area have less than 30 percent of ilmenite (A. M. White, written commun., 1954). Concentrates from tributaries to North Muddy Creek commonly have about 50 percent of ilmenite. Magnetite makes up 5–10 percent of the concentrate from alluvium in the extreme eastern part of the basin and increases in abundance toward the west. It makes up as much as 70 percent of the concentrate in the Demming area. Epidote is virtually absent from concentrates from Glade Creek and the head of South Muddy Creek, but elsewhere concentrates contain 1–10 percent of epidote and locally 30 percent. Rutile forms less than 1 percent of the minerals in concentrates throughout the basin. Sillimanite is scarce and sporadically distributed; it constitutes 1 percent of the concentrate at several isolated places along North Muddy Creek and Shadrick Creek. Kyanite is present in low percentages in concentrates from the northern tributaries to North Muddy Creek. Garnet occurs in most concentrates in small amounts, and hornblende is very common. Attention was early called to the common presence of xenotime in the placers around Demming and Gum Branch (Dennis, 1898, p. 494; Zodac, 1958).

Long, broad, and continuous flood plains on South Muddy Creek extend into the headwaters of the stream around Dysortville. The flood plains on South Muddy Creek join large but less continuous flood plains in the lower valley of North Muddy Creek. Most of the central part of the valley of North Muddy Creek lacks extensive fill, but for a few miles downstream from Glenwood and along headwater tributaries upstream from Glenwood the valleys have broad and continuous flood plains.

The headwater parts of North Muddy Creek and South Muddy Creek were mined for placer monazite in the late 1800's and early 1900's (Nitze, 1895c; Pratt, 1902, p. 60). Long Branch, Alexander Branch, MacLawrath Branch, Gum Branch, the Dysortville area, and the Demming area were mentioned as sites of former mining, but apparently the large valleys were not mined. Most of the gold in this area was said to be mined out by 1905 (Pardee and Park, 1948, pl. 14). These valleys along with the small streams were appraised by A. M. White in the summer of 1952, and the large flood plain on South Muddy Creek was drilled by the U.S. Bureau of Mines in October of that year (Hansen and White, 1954, p. 4). White estimated that the basin of Muddy Creek contained at least 18,500 short tons of monazite in alluvium having an average tenor of 0.6 pounds of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711). According to White, this resource is mainly in South Muddy Creek and its tributaries, particularly the part of the basin around Dysortville (A. M. White, written commun., 1954):

	Average tenor (lb of monazite per cu yd)	*Resources in monazite (short tons)*
Shadrick Creek	0.5	420
Glade Creek and Camp Branch	.6	1,350
North Muddy Creek to mouth of Glade Creek	.4	600
North Muddy Creek from mouth of Glade Creek to Caleb Branch	.3	950
Lower part of North Muddy Creek including tributary from Nebo	.4	1,600
South Muddy Creek and Katy Creek	.7	1,400
Southeast Muddy Creek and Magazine Branch to a point 3,000 feet downstream from mouth of Magazine Branch (Dysortville area)	1.5	5,000
South Muddy Creek from mouth of Katy Creek to a point 4,500 feet downstream from mouth of Long Branch including Alexander Branch, Southeast Muddy Creek from a point 3,000 feet downstream from Magazine Branch, and Long Branch	.8	4,100
South Muddy Creek from a point 4,500 feet downstream from mouth of Long Branch to confluence with North Muddy Creek, and Muddy Creek to the Catawba River	.4	1,750
Other streams	--------	1,330
Total	--------	18,500

These tenors are, of course, substantially lower than the tenors of gravel in the small streams formerly mined for monazite. Gravel from Alexander Branch was found by Mertie (1953, p. 8, 10) to contain 5.4 pounds of monazite per cubic yard.

The large flood plain on South Muddy Creek downstream from Southeast Muddy Creek to a point about 1.3 miles upstream from the confluence with North Muddy Creek was explored by the U.S. Bureau of Mines and found to contain about 5,800 short tons of monazite in alluvium having an average tenor of 0.6 pound of monazite and 3–5 cents worth of gold per cubic yard (Hansen and White, 1954, p. 6). Eleven churn-drill holes in the flood plain disclosed that the weathered bedrock floor of the valley is remarkably level, that the flood plain sediments are 15.5–19.0 feet thick, and that the sediment is mainly fine grained. The amount of monazite in the alluvium was found to decrease from about 0.75 pound per cubic yard in the upstream part of the area explored to about 0.5 pound in the downstream part of the flood plain. The average amount of black sand is 8 pounds per cubic yard consisting of the following percentages of the concentrate (Hansen and White, 1954, p. 15):

	Percent		Percent
Epidote	17	Monazite	6.4
Ilmenite	23	Rutile	0.1-0.5
Quartz	21	Sillimanite and kyanite	Trace
Garnet	5	Xenotime	1
Hornblende	6	Sphene	1
Magnetite	9		
Zircon	8		

Very small amounts of pyrite, spinel, tourmaline, and mica are also present. Inferred reserves of other components in the black sand were estimated to be 18,300 short tons of ilmenite, 4,100 short tons of garnet, and 6,300 short tons of zircon (Hansen and White, 1954, p. 24).

High-grade monazite concentrates from Gum Branch were said to contain 3.30 percent of ThO_2 (Nitze, 1895c), and commercial concentrates from Long Branch, Alexander Branch, and MacLawrath Branch were reported by Pratt (1902, p. 60) to contain 1.27, 6.30, and 2.48 percent of monazite respectively. Monazite from Alexander Branch was analyzed by the U.S. Geological Survey and found to contain 3.60 percent of ThO_2 and 0.27 percent of U_3O_8 (Mertie, 1953, p. 8, 12). An analysis of monazite from South Muddy Creek was reported by the U.S. Bureau of Mines to disclose 4.3 percent of ThO_2 and 0.36 percent of U_3O_8 (Hansen and White, 1954, p. 21).

RUTHERFORD, POLK, AND CLEVELAND COUNTIES

Fluvial gold placers near Rutherfordton in Rutherford County were the source in 1849 of the first monazite described from North Carolina (Shepard, C. U., 1849, p. 275; 1852, p. 109). In later years, around 1890, when an independent monazite mining industry developed in the State, gold placers in the headwaters of the Second Broad River and First Broad River in and along the south flank of the South Mountains in Rutherford County and Cleveland County were the source of some monazite (Nitze, 1895c; Pratt, 1903, p. 181). Similarly, fluviatile gold placers were the first sites of monazite mining in Polk County, where the Morris mine and Prince mine near Sandy Plains were worked for monazite in the late 1800's (Genth and Kerr, 1881, p. 115; Genth, 1891, p. 86). At many gold placers the concentrates contained large quantities of magnetite, epidote, and hornblende derived from hornblende gneiss. Processing these concentrates for monazite would have been uneconomic had not the extra cost been offset by the value of the gold (Pratt, 1907b, p. 113). As the monazite industry developed gold placers were abandoned and fluviatile deposits that were workable for monazite alone were opened. Placers mined strictly for monazite characteristically have little or no magnetite, epidote, hornblende, or gold. These placers lie to the southeast of the monazite-bearing auriferous deposits. They occur in the core of the monazite belt, whereas the auriferous placers are along the northwest flank of the belt.

The monazite placers in Rutherford County and Cleveland County were among the most productive in the State and probably accounted for at least half the monazite mined in North Carolina. Records by county are not available, but Cleveland County was probably the greatest producer (table 58). The output of monazite in Polk County apparently was an insignificant part of the total. Frequently mentioned centers for the monazite-mining industry were Rutherfordton, Ellenboro, Oak Springs, Bostic, Spindale, and Henrietta in Rutherford County (Pratt, 1903, p. 182; 1904c, p. 35; Drane and Stuckey, 1925, p. 19; Bryson, 1927, p. 15–16); Sandy Plains in Polk County (Genth, 1891, p. 86); and Belwood, Carpenter Knob, Casar, Lawndale, Mooresboro, and Shelby in Cleveland County (Nitze, 1895c; Sterrett, 1908b, p. 281; Drane and Stuckey, 1925, p. 19; Bryson, 1927, p. 15–16).

During the life of the monazite industry the most thorough studies of the geology of the placers were made by Sterrett (1908b, p. 273–280) and Pratt and Sterrett (1908a), who described the small size and sparseness of gravel in individual placers but wide geographic distribution of the deposits. After the industry closed in 1917, scant attention was paid to the deposits until the 1940's and 1950's, although a little prospecting and development were done in Cleveland County between 1929 and 1936 (Bryson, 1937, p. 132). In 1943 and 1944 nearly two dozen placers in Rutherford County and Cleveland County were examined by members of the Regional Products Research Division of the Tennessee Valley Authority, and the deposits were seen to constitute a minable resource under conditions of critical short supply (McDaniel, 1943; Lefforge and others, 1944). During 1945, Mertie (1953, p. 7–12) sampled 9 placers in Rutherford County and 21 in Cleveland County. He found that the tenor of the gravel in deposits in Rutherford County ranged from 5.1 to 26.5 pounds of monazite per cubic yard and in deposits in Cleveland County from 3.1 to 48.3 pounds of monazite per cubic yard. The average tenor of gravel in the 9 placers in Rutherford County was found to be 13.1 pounds of monazite per cubic yard and in the 21 placers in Cleveland County 12.2 pounds per cubic yard. Thorium oxide in detrital monazite was reported by Mertie (1953, p. 12) to range from 4.47 to 5.80 percent and to average 5.16 percent in 9 samples from Rutherford County and to range from 4.62 to 7.84 percent and to average 6.19 percent in 21 samples from Cleveland County. Between 1951 and 1954 the monazite-bearing streams in Rutherford, Polk, and Cleveland Counties were examined by P. K. Theobald, Jr., J. W. Whitlow, A. M. White, and the writer, all of the U.S. Geological Survey, for the U.S. Atomic Energy Commission. As a result of this appraisal the resources in monazite in the three counties were estimated to be at least 285,000 short tons of monazite in fluvial sediments having an average tenor of 1.0 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711). This examination also disclosed the distribution of monazite and other heavy minerals in the three counties.

Monazite is present in concentrates from alluvium in most streams in Rutherford County, except those in the extreme northwestern part (Overstreet, 1962, fig. 2). It occurs in concentrates from alluvium in the southeast corner of Polk County. Concentrates from stream sediments throughout Cleveland County, except the extreme southeastern part, are monazite bearing. In Rutherford and Cleveland Counties the core of the monazite belt attains its maximum width of 26 miles, and the belt itself is 40 miles wide. The northwest edge of the core of the belt extends northeastward from the south edge of Polk County at a point about 4 miles west of the Rutherford County line. It then passes about 2 miles east of Rutherford on to the mutual boundary of Rutherford County, Cleveland County, and Burke County in the South Mountains. Southeast of this line across Rutherford County and almost all of Cleveland County, concentrates from alluvium contain 10–40 percent of monazite and very locally as much as 60 percent. The northwest flank of the belt, which is marked by concentrates having as much as 10 percent of monazite, is 10–14 miles across in Rutherford and Polk Counties, but the southeast flank in Cleveland County is only 1–5 miles wide.

Rutile is present in slightly more than half the concentrates from alluvium in the core of the monazite belt in Rutherford, Polk, and Cleveland Counties, but it is virtually absent from concentrates from the flanks. It is most commonly present in concentrates from eastern Rutherford County, extreme southeastern Polk County, and southwestern, central, and northwestern Cleveland County. In most of these places rutile makes up 1–5 percent of the concentrate, but in central Cleveland County it makes up 5–10 percent.

Sillimanite makes up from 1 to 5 percent of the heavy minerals in concentrates from the core of the monazite belt, but it is absent from concentrates from streams on the flanks of the belt. Over most of central Cleveland County and in the southwest corner of the county, concentrates contain 5–10 percent of sillimanite, and locally they have as much as 15–25 percent. Along the central part of the south edge of Rutherford County, concentrates are devoid of sillimanite. On the southeast flank of the monazite belt at the south edge of Cleveland County, sillimanite is accompanied by kyanite (Overstreet and Griffitts, 1955, fig. 1).

Almandine and ilmenite are much more common in concentrates from alluvium in the core of the belt than in concentrates from the flanks. Most concentrates from eastern Rutherford County and western Cleveland County contain 5–15 percent of garnet and 50–70 percent of ilmenite. Elsewhere the percentages are lower.

Epidote is common in concentrates from alluvium along the northwest flank of the monazite belt in Rutherford County and Polk County, but it is virtually absent from the core of the belt. It is absent from concentrates from the southeast flank of the belt in Cleveland County. Staurolite is very common in concentrates from the southeast flank but is virtually absent elsewhere (Overstreet and Griffitts, 1955, fig. 1).

Magnetite rarely makes up more than 1 percent of the heavy minerals in concentrates from alluvium in the core of the belt or from alluvium in the southeast flank in Cleveland County, but it is present in amounts of from 5 to 50 percent of concentrates along the northwest flank in Rutherford County and Polk County. Locally as much as 80 percent of the minerals in the concentrate is magnetite.

Hornblende is generally present in concentrates from the northwest flank of the belt in Rutherford and Polk Counties, and it rises to a peak abundance of 40 percent in concentrates from auriferous areas along the southern slopes of the South Mountains in Rutherford County, but it is not present in concentrates from the core of the belt. Concentrates from the southeast flank of the belt in Cleveland County contain as much as 5 percent of hornblende (Overstreet and Griffitts, 1955, fig. 1).

The appraisal of resources of monazite in the three counties was based on the study of eight drainage basins or groups of basins (Overstreet, Theobald, and Whitlow, 1959, p. 711): Mountain Creek, Catheys Creek, Floyds Creek, Hinton Creek, McKinney Creek, Knob Creek, Sandy Run, and Buffalo Creek. The first four basins are mainly in Rutherford County; the McKinney Creek area includes parts of Rutherford and Polk Counties; and the last three basins are principally in Cleveland County.

Mountain Creek and other tributaries to the Broad River in west-central Rutherford County were estimated by Theobald to contain at least 6,800 short tons of monazite in flood-plain sediments having an average tenor of 0.5 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711). Flood plains in the area are small and disconnected. The streams are on the northwest flank of the monazite belt in an area where concentrates consist dominantly of magnetite, epidote, and hornblende.

The Catheys Creek area includes Cane Creek and other streams constituting the upstream half of the Second Broad River in north-central Rutherford County and southeastern McDowell County. These streams rise on the south side of the South Mountains opposite the headwaters of Muddy Creek and Silver Creek. Most of the area drained by Catheys Creek and adjoining tributaries to the Second Broad River is on the northwest flank of the monazite belt; only the southeasternmost part of the area is in the core of the belt. Magnetite, epidote, and hornblende are the most common minerals in concentrates. The average tenor of flood plain sediments was estimated by Theobald (Overstreet, Theobald, and Whitlow, 1959, p. 711) to be 0.7 pound of monazite per cubic yard, and the resources in monazite were said to be at least 36,800 short tons.

Four holes were drilled by the U.S. Bureau of Mines during February 1952 in the flood plain at the confluence of Catheys Creek with the Second Broad River, and three holes were drilled in the lower and middle reaches of Cane Creek. Results of the drilling on Catheys Creek showed that the alluvium ranged in thickness from 19 to 23.5 feet and contained from 6.52 to 14.35 pounds of black sand per cubic yard including 0.27–0.91 pound of monazite and persistent small amounts of gold (R. F. Griffith, written commun., 1952). Results of the drilling on Cane Creek showed that the flood-plain sediments ranged in thickness from 17.5 to 21 feet and contained from 12.30 to 16.49 pounds of black sand per cubic yard having 0.38–0.52 pound of monazite and small amounts of gold. Cane Creek has the longest, largest, and most continuous flood plain in the area. In volume, tenor, and presence of gold the alluvium in the valley of Cane Creek resembles that in Muddy Creek and Silver Creek. Also, several gold placers at the head of Cane Creek were said to have been mined out by 1905 (Pardee and Park, 1948, pl. 14).

Two samples of monazite from Hollands Creek, a principal tributary to Catheys Creek, were analyzed by the U.S. Geological Survey and reported by Mertie (1953, p. 12) to contain 5.27 and 5.49 percent of ThO_2 and 0.22 and 0.25 percent of U_3O_8.

Floyds Creek and several small tributaries to the Broad River in southeastern Rutherford County were estimated by P. K. Theobald, Jr., to contain at least 42,700 short tons of monazite in sediments which along the small streams have an average tenor of 1.1 pounds of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711). The area is in the core of the monazite belt and concentrates have as much as 50 percent of monazite (Overstreet, 1962, fig. 2). Ilmenite and garnet are invariably present in the concentrates, sillimanite is present in about 85 percent of the concentrates, and rutile occurs in about half of them (P. K. Theobald, Jr., written commun., 1954). Magnetite, epidote, and hornblende are scarce except in the westernmost streams which rise on the flank of the monazite belt.

The largest volume of alluvium in the Floyds Creek area was reported (P. K. Theobald, Jr., written commun., 1954) to be in discontinuous flood plains along the Second Broad River and in long, continuous flood plains in the valleys of south-flowing tributaries to the Second Broad River, principally Robinson Creek, Heaveners Creek, Hunting Creek, Puzzle Creek, and Webb Creek. East-flowing tributaries to the Second Broad River are very small, and south-flowing tributaries to the Broad River, of which Floyds Creek is one, have small, discontinuous flood plains. According to Theobald, the average tenor of the alluvium and the resources in monazite in the valleys of these streams are as follows:

	Average tenor (lb of monazite per cu yd)	Resources (short tons)
Second Broad River	0.5	7,000
Robinson Creek and Heaveners Creek to to the mouth of Heaveners Creek	1.4	6,800
Robinson Creek from the mouth of Heaveners Creek to the Second Broad River	1.7	6,500
Hunting Creek	3.2	1,300
Puzzle Creek	3.2	4,600
Webbs Creek	2.7	2,500
Floyds Creek	1.1	5,500
Other streams	--------	8,500
Total	--------	42,700

Gold was formerly mined in the area around the head of Robinson Creek. The mouth of the creek is near Bostic and east of Spindale; both communities were at one time noted centers for monazite placer mining. Puzzle Creek passes east of Bostic, and Webbs Creek lies west of Ellenboro, another of the frequently cited centers for monazite mining in Rutherford County. Many small streams not impressive for the size of their valleys but apparently mined in a small way are around Henrietta.

Monazite sand from Henrietta was said by Pratt (1903, p. 182) to contain 1.93 percent of ThO_2. Seemingly the reference is to a rough concentrate, because a sample of monazite from a short tributary to the Second Broad River about 2 miles north of Henrietta was reported by Mertie (1953, p. 12) to have 4.74 percent of ThO_2 and 0.64 percent of U_3O_8. Two samples of monazite from Webbs Creek were said by Mertie to contain 4.47 and 5.76 percent of ThO_2 and 0.34 and 0.40 percent of U_3O_8.

Hinton Creek and other headwater tributaries to the First Broad River rise in northeastern Rutherford County and northwestern Cleveland County on the south side of the South Mountains. The northwesternmost headwater branches of the First Broad River, streams called Sally Queen Creek, Hardbargain Branch, Beatty Creek, Molly Fork, and South Creek, rise along the northwest edge of the core of the monazite belt in an area where concentrates from alluvium contain copious garnet and ilmenite associated with some sillimanite and low percentages of magnetite, epidote, and hornblende (Overstreet and Griffitts, 1955, fig. 1). Most of these streams were formerly mined for gold; some were mined out by 1905 (Pardee and Park, 1948, pl. 14). East of the mouth of South Creek, alluvium in the principal tributaries to the First Broad River, known as Brier Creek, Duncans Creek, and Hinton Creek, contains little or no magnetite, epidote, hornblende, and gold. Concentrates from these streams consist mainly of garnet, ilmenite, monazite, and sillimanite. Alluvium along these streams was estimated by P. K. Theobald, Jr., to contain at least 39,000 short tons of monazite and to have an average tenor of 1.3 pounds of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711). These resources were inferred by Theobald (written commun., 1954) to be mainly in the First Broad River, Duncans Creek, and Hinton Creek:

	Average tenor (lb of monazite per cu yd)	Resources (short tons)
Molly Fork	1.2	400
Hardbargain Branch	.8	400
Somey Creek and the upper part of the First Broad River	1.2	1,500
North Fork	.4	300
South Creek	1.2	1,600
First Broad River for a distance of 3.5 miles downstream from mouth of North Fork	.7	3,500
First Broad River from the above locality to the mouth of Brier Creek	2.4	6,000
Brier Creek	.8	600
Duncans Creek	2.3	11,000
First Broad River from 0.75 mile east of the Rutherford County line to the mouth of Hinton Creek	.8	5,500
Hinton Creek	1.6	8,000
Other streams	--------	200
Total	--------	39,000

During the winter of 1951 and the late fall of 1952 the U.S. Bureau of Mines sank 52 churn-drill holes in the flood plain of the First Broad River between Hinton Creek and a point 1.4 miles above the mouth of Duncans Creek and in contiguous alluvium along the lower parts of Hinton, Duncans, and Wards Creeks in Cleveland County just downstream from the Rutherford County line (Hansen and Cuppels, 1954, p. 10). Results of the drilling showed that the flood plain sediments contain about 7,200 short tons of monazite (table 71). From 2 to 3 percent of epidote was present in concentrates from the First Broad River, and 1 percent was observed in concentrates from Wards Creek, but only a trace was present in black sand from Hinton Creek and Duncan Creek (Hansen and Cuppels, 1954, p. 17). Only traces of magnetite were found.

TABLE 71.—*Reserves of monazite and other minerals in alluvium in the valley of the First Broad River and contiguous parts of the valleys of Wards Creek, Duncans Creek, and Hinton Creek, Cleveland County, N.C.*

[Modified from Hansen and Cuppels (1954, p. 5, 10, 14, 24). Symbols used: --, absent; NA, not applicable]

Feature	First Broad River	Wards Creek	Duncans Creek	Hinton Creek	Total
Number of churn drill holes	24	11	6	11	52
Minable material:					
Thickness feet	24	18	28	18	NA
Tenor lb monazite per cu yd	.85	.72	.74	.72	NA
Gravel:					
Thickness feet	7	9	13	5	NA
Tenor lb monazite per cu yd	1.2	1.2	1.5	1.5	NA
Volume of alluvium thousands of cu yd	9,681	3,183	1,648	3,750	18,262
Partial composition of concentrate (percent):					
Monazite	7.8	8.8	3.2	6.5	NA
Ilmenite	31	40	24	35	NA
Garnet	31	27	14	26	NA
Sillimanite and kyanite	12	10	16	13	NA
Zircon	3.5	3.5	--	3.5	NA
Rutile	2	1.5	--	4.5	NA
Reserves (short tons):					
Monazite	4,115	1,140	610	1,353	7,218
Ilmenite	30,000	8,000	5,000	7,000	50,000
Garnet	30,000	5,500	2,500	5,000	43,000
Sillimanite and kyanite	12,000	2,000	3,000	2,600	19,600
Zircon	3,400	700	--	700	4,800
Rutile	2,000	300	--	900	3,200

Monazite from the area drilled was analyzed by the U.S. Bureau of Mines and was reported to contain the following percentages of thorium oxide (Hansen and Cuppels, 1954, p. 21):

	Percent	
	ThO_2	U_3O_8
First Broad River	5.91	0.50
Wards Creek	5.94	.76
Duncans Creek	6.66	.62
Hinton Creek	5.42	.59

Two samples of monazite from southern tributaries to Duncans Creek at localities 1⅞ miles and 2⅜ miles north of Hollis, Rutherford County, were analyzed by the U.S. Geological Survey and reported to have respectively 5.28 and 5.02 percent of ThO_2 and 0.33 and 0.28 percent of U_3O_8 (Mertie, 1953, p. 12).

Early predictions that every stream in Polk County would prove to be monazite bearing (Genth and Kerr, 1881, p. 84) were not borne out, and later investigations showed that monazite is common only in the eastern part of the county (Eng. and Mining Jour., 1888, p. 2; Nitze, 1895c). Much of the monazite in the Sandy Plains area in south-central Polk County is in auriferous placers on tributaries to the Pacolet River that rise south of the divide on which Sandy Plains is located and flow into South Carolina (Genth and Kerr, 1881, p. 115; Genth, 1891, p. 86; Pardee and Park, 1948, p. 85). Tributaries to the Broad River north and east of Sandy Plains are also monazite bearing. The largest of these streams in Polk County are Wheat Creek, Machine Creek, Whiteoak Creek, Mill Creek and Greens Creek, which enter the Green River, a major southern tributary to the Broad River, and McKinney Creek which is confluent with the Broad River in Rutherford County. An estimate prepared by A. M. White showed that these streams have at least 3,600 short tons of monazite in alluvium having an average tenor of 0.5 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711).

Only the easternmost streams, Greens Creek and McKinney Creek, are in the core of the monazite belt. Alluvium in these two streams was estimated by A. M. White (written commun., 1954) to have average tenors of 1.1 and 0.7 pounds of monazite per cubic yard, respectively. The other streams are on the northwest flank of the monazite belt; their alluvium was estimated by White to have the following average tenors:

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Wheat Creek	0.1	30
Machine Creek	.4	115
Whiteoak Creek	.3	1,500
Mill Creek	.6	270
Greens Creek	1.1	900
McKinney Creek	.7	650
Other streams	--------	135
Total	--------	3,600

None of these streams was an important source of monazite, and Polk County contributed little to the State output of monazite.

Knob Creek and other tributaries to the First Broad River in Cleveland County downstream from Wards Creek to Big Harris Creek were estimated by P. K. Theobald, Jr., to have at least 45,000 short tons of monazite in alluvium which has an average tenor of 2.1 pounds of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711). The high average tenor of alluvium in the Knob Creek area is equaled elsewhere in the western monazite belt only by alluvium in Huff Creek and adjacent streams in the drainage basin of the Reedy River in Greenville County, S.C. (Overstreet, Theobald, and Whitlow, 1959, p. 710). Knob Creek, like the Huff Creek area, is in part of the core of the monazite belt where most concentrates contain 20–40 percent of monazite although some contain 60 percent (Overstreet, 1962, fig. 2). Biotite schist and gneiss, sillimanite schist, and quartz monazite are the principal varieties of rocks underlying the drainage basins in the Knob Creek area. Concentrates that have the greatest amount of monazite come from basins underlain by quartz monzonite and sillimanite schist. For the most part the concentrates consist mainly of garnet, monazite, ilmenite, sillimanite, and rutile, but at several places where gabbro and hornblende gneiss are present, as on Bob Branch and near the heads of Maple Creek and Wards Creek, magnetite is common.

Most of the flood plains in the Knob Creek area, including those in the valley of the First Broad River, are narrow and discontinuous (P. K. Theobald, Jr., written commun., 1954). The broadest flood plains are at the confluence of Big Knob Creek and Little Knob Creek where a maximum width of about 1,000 feet is attained. Many of the narrow flood plains extend far up toward the sources of the streams. The thickness of gravel in the sequence of flood plain sediments remains about the same from the main valleys to the heads of the streams, but the silt and clay above the gravel decreases headward to about one-third its thickness in the main valleys. Mostly the basal gravel is about 0.5–1.5 feet thick, and the overlying clay, silt, and sand ranges in thickness from a maximum of about 15 feet in the main streams to 2–5 feet in the headwaters. In the Knob Creek area the flood plain sediments consist of about 17 percent gravel, 23 percent clay, and 60 percent sand and silt.

Riffle gravel from about one-third of the streams in the area was reported by P. K. Theobald, Jr. (written commun., 1954) to contain 5 pounds or more of monazite per cubic yard, and the maximun tenor observed was 31.7 pounds of monazite per cubic yard. Seven out of ten samples of riffle gravel panned by Mertie (1953, p. 10) from formerly mined creeks in the area contained from 7.8 to 30.4 pounds of monazite per cubic yard. The average tenor of the flood plain sediments between grass roots and bedrock was found by Theobald to be appreciably less than 5 pounds of monazite per cubic yard except along Crooked Run Creek:

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Wards Creek	1. 6	6, 000
Stoney Run Creek	4. 4	1, 600
Grassy Branch	2. 4	1, 200
Crooked Run Creek	5. 9	6, 500
Big Knob Creek	2. 4	14, 000
Poundingmill Creek	3. 6	1, 900
Bob Branch	3. 1	1, 700
Little Knob Creek	2. 0	6, 400
Knob Creek	. 6	900
Maple Creek	. 6	900
Magness Creek	. 9	350
Big Harris Creek	2. 1	650
Little Harris Creek	1. 7	700
First Broad River	. 7	1, 900
Other streams	--------	300
Total	--------	45, 000

The large flood plain on Big Knob Creek extending for 2 miles upstream from the mouth of Poundingmill Creek was drilled by the U.S. Bureau of Mines in November and December 1951 and was found to contain 3,330,000 cubic yards of minable alluvium having 2,780 short tons of monazite, 11,700 short tons of garnet, 7,700 short tons of ilmenite, and 330 short tons of zircon (Griffith and Overstreet, 1953a, p. 4–5). The average tenor in monazite is 1.67 pounds of monazite per cubic yard of alluvium. Gravel at the base of the sequence of flood plain deposits is about four times richer in monazite than the overlying fine sand and silt, but even those sediments contain about 0.9 pound of monazite per cubic yard.

One hole was drilled to a depth of 20.5 feet in colluvium on a spur of Carpenter Knob 1 mile north of the north end of the explored flood plain. The average tenor of the colluvium sampled at this site is 1.83 pounds of monazite per cubic yard (Griffith and Overstreet, 1953a, p. 18). Seven samples of colluvial subsoil from the drainage basin of Knob Creek were reported by J. W. Whitlow (written commun., 1954) of the U.S. Geological Survey to have the following average tenor:

[Computed by J. W. Whitlow from mineralogical analyses by M. N. Girhard, H. B. Groom, Jr., R. P. Marquiss, C. J. Spengler, Jerome Stone, and E. J. Young of the U.S. Geological Survey]

Laboratory No.	*Tenor (lb of monazite per cu yd)*
88476	1. 6
90320	. 2
90321	. 2
90331	6. 8
90332	2. 8
90357	. 1
90358	10. 1
Average	3. 1

Monazite sands of undescribed purity from the Carpenter Knob area and Belwood were reported by Pratt (1903, p. 182) to have respectively 6.26 and 5.87 percent of ThO_2. In 1908 an analysis was made of monazite concentrate thought by L. G. Houk to be from Belwood in the Knob Creek area, but the amount of thorium oxide is very much lower than any known from this district:

[Analyst: G. P. T. Chernik in 1908 (in Houk, 1946, p 3)]

	Percent		*Percent*
Ce_2O_3	45. 40	FeO	3. 62
$(La, Nd, Pr)_2O_3$	6. 56	Fe_2O_3	5. 58
Y_2O_3	2. 07	ZrO_2	3. 25
ThO_2	1. 22	$(Nb, Ta)_2O_5$	4. 12
P_2O_5	23. 43	MnO	Trace
SiO_2	1. 60		
Al_2O_3	2. 49	Total	99. 34

Analyses were made by the U.S. Geological Survey of monazite collected by Mertie (1953, p. 12) in 1945 at placers in the Knob Creek area. Results of these analyses showed that monazite from Knob Creek and vicinity contained from 5.08 to 7.84 percent of ThO_2:

	Percent ThO_2	Percent U_3O_8
Poundingmill Creek	6.80	0.39
Big Knob Creek	7.00	.29
Bald Knob Creek	5.66	.36
Little Knob Creek	7.84	.35
Knob Creek	7.06	.34
Knob Creek	5.08	.40
Maple Creek	7.22	.28
Grassy Branch	5.31	.49
Crooked Run Creek	7.54	.37
Crooked Run Creek	6.45	.32

Monazite from the drilled area on Big Knob Creek was analyzed by the U.S. Bureau of Mines and found to contain 7.28 percent of ThO_2 and 0.42 percent of U_3O_8 (Griffith and Overstreet, 1953a, p. 26). The results of these analyses, plus the ones made on monazite separated from crystalline rocks in this part of Cleveland County and previously cited (tables 64–68), indicate that the material analyzed by Chernik and attributed by Houk to sources around Belwood is too lean in thorium oxide to have come from that area.

Sandy Run rises in eastern Rutherford County and flows southeastward into Cleveland County where it enters the Broad River. Its extreme headwaters are on the northwest flank of the monazite belt, but for most of its length Sandy Run is in the sillimanitic core of the monazite belt. Immediately east of Sandy Run are two large streams known as Brushy Creek and Beaverdam Creek. They are western tributaries to the First Broad River. Both of these streams drain part of the core of the monazite belt, and concentrates from sediments in their valleys, like concentrates from most parts of Sandy Run, contain 10–30 percent of monazite, abundant ilmenite and garnet, and accessory rutile and sillimanite. Epidote is absent and magnetite is sparse. Concentrates from the extreme head of Sandy Run east of Hopewell contain only 5–10 percent of monazite. Alluvium in small branches and creeks in the headward parts of these streams was formerly mined by hand methods for detrital monazite. Most of the mining was along branches of Sandy Run in the vicinity of Hopewell, Lattimore, Mooresboro, and Ellenboro, Brushy Creek south of Polkville, and Beaverdam Creek east of Lattimore. The German-American Monazite Co. was reported to have mined a headwater tributary to Sandy Run about 1⅛ miles north-northwest of Hopewell (Mertie, 1953, p. 8).

Monazite sand of unknown tenor from the Davis mine near Mooresboro was said to have 3.98 percent of ThO_2 (Pratt, 1903, p. 182). Somewhat more thorium oxide than this seems to be characteristic of pure monazite from the area. Sampling in 1943 and 1945 of formerly mined placers on Sandy Run, Brushy Creek, and Beaverdam Creek showed that gravel in these deposits contained from 3.6 to 26.5 pounds of monazite per cubic yard and that the monazite had from 4.58 to 5.86 percent of ThO_2 (Lefforge and others, 1944; Mertie, 1953, p. 7–8, 10, 12).

Monazite from placers in Cleveland County

[Analyst: U.S. Geol. Survey except first entry, which was by Dept. Chem. Eng., Tenn. Valley Authority]

Stream	Tenor of riffle gravel (lb of monazite per cu yd)	Composition of monazite (percent) ThO_2	U_3O_8
Sandy Run	----------	5.15	----------
	4.5	5.58	0.33
	12.8	5.86	.28
	5.5	5.52	.31
	12.7	5.80	.28
	26.5	4.58	.33
Brushy Creek	3.6	5.06	.53
	10.6	4.62	.55
Beaverdam Creek	8.9	5.08	.54
Average of above	10.6	5.25	.39

An appraisal of Sandy Run, Brushy Creek, and Beaverdam Creek was made in the summer of 1951 by P. K. Theobald, Jr., of the U.S. Geological Survey, who estimated that the valleys of the streams contained at least 66,300 short tons of monazite in sediments having an average tenor of 1.6 pounds of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711). Theobald observed that sediments having the highest tenor (written commun., 1954) were in valleys at the head of Sandy Run from Hopewell southeast to Lattimore and southwest to Ellenboro, in the northern tributaries to Brushy Creek east of Washburn, and at the head of Beaverdam Creek southeast of Lattimore:

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Sandy Run headwaters east of Hopewell and south to mouth of Mayne Creek	3.5	15,200
Mayne Creek	3.8	5,000
West Fork west of Hopewell and south to Sandy Run near mouth of Mayne Creek	2.0	11,400
Sandy Run from Mayne Creek to the Broad River	1.4	8,600
Grog Creek	.5	900
Brushy Creek headwaters to mouth of Little Creek	1.4	4,900
Little Creek	2.6	900

	Average tenor (lb of monazite per cu yd)	Resources (short tons)
Northern tributaries to Brushy Creek east of Washburn	3.0	1,900
Brushy Creek from Little Creek to the First Broad River	.6	2,300
Beaverdam Creek headwaters including Sugar Branch	1.6	6,000
Lower part of Beaverdam Creek	1.3	2,000
Yancey Creek	2.3	900
Other streams	--------	6,300
Total	--------	66,300

An area of connected flood plains near the head of Sandy Run at a point 0.9 mile east of Hopewell was explored by the U.S. Bureau of Mines in January and February 1952 (Griffith and Overstreet, 1953c, p. 4–5). Results of the drilling showed that the average tenor of the gravel in the lower one-third of the sequence of flood plain sediments is 3.3 pounds of monazite per cubic yard and that the silt and fine sand overlying the gravel and making up two-thirds of the section of sediment has an average tenor of 1 pound of monazite per cubic yard. From grass roots to bedrock the average tenor was estimated to be 1.63 pounds of monazite per cubic yard. The explored flood plains were estimated to contain 4 million cubic yards of sediment with combined indicated and inferred reserves of 3,300 short tons. The mineralogical composition of a composite concentrate prepared from alluvium sampled at 30 drill holes in the headwaters of Sandy Run 0.9 mile east of Hopewell is as follows:

[Modified from Griffith and Overstreet (1953c, p. 21)]

	Percent		Percent
Epidote	Trace	Zircon	0.5
Hornblende and biotite	0.5	Sillimanite	13.3
Garnet	26.5	Kyanite	2.7
Ilmenite	34.3	Monazite and xenotime	6.1
Magnetite	.5		
Quartz	8.5		
Rutile	5.4	Total	98.3

Monazite from the explored area at the head of Sandy Run was analyzed by the U.S. Bureau of Mines and found to contain 4.63 percent of ThO_2 and 0.80 percent of U_3O_8 (Griffith and Overstreet, 1953c, p. 25).

Hickory Creek, an eastern tributary to the First Broad River in Cleveland County, was frequently mentioned in the early literature as the site of lode mining for monazite by the British Monazite Co. at the L. U. Campbell placer mine about 3 miles northeast of Shelby (Pratt, 1901, p. 31; 1907b, p. 118–119; Sterrett, 1907b, p. 1204–1205; Keith and Sterrett, 1931, p. 10). Present riffle gravel in Hickory Creek at the L. U. Campbell mine was reported by Mertie (1953, p. 7, 10) to contain 3 pounds of monazite per cubic yard, and gravel from a riffle on Little Hickory Creek at a point about 2 miles south of the L. U. Campbell mine was found by Mertie to have 3.9 pounds of monazite per cubic yard. Presumably, monazite in the gravel at the mine was replenished between the time mining ceased around 1906 and 1945 when the gravel was sampled. Source of the replenishing monazite was principally the soil on hillsides adjacent to the stream. Analyses of detrital monazite from Hickory Creek at the L. U. Campbell mine and from Little Hickory Creek were made by the U.S. Geological Survey and showed 7.72 and 5.77 percent of ThO_2 and 0.33 and 0.98 percent of U_3O_8, respectively (Mertie, 1953, p. 12).

Buffalo Creek rises in the northwest corner of Lincoln County, flows southward through parts of Cleveland County and Gaston County, and enters the Broad River in Cherokee County, S.C. Most of its course is in Cleveland County. The headwaters of the stream originate in the core of the monazite belt, and as far south as the divide it shares with Hickory Creek in the vicinity of Stubbs, the stream and its tributaries are in the core of the belt. South of Stubbs the stream passes into the southeast flank of the monazite belt, and its eastern tributaries rise either in the flank of the belt or outside the belt. Where Buffalo Creek is in the core of the belt, concentrates from sediment in the valley contain 10–30 percent of monazite and locally as much as 60 percent. Concentrates from alluvium in the part of the stream on the flank of the belt have less than 10 percent of monazite, and those from the eastern tributaries south of Stubbs have either a trace of monazite or are barren.

Rutile is common in concentrates from alluvium in the northern and central parts of the basin of Buffalo Creek, as much as 10 percent of rutile being present in a few concentrates. Sillimanite is also particularly abundant in concentrates in this part of the basin (Overstreet, 1962, fig. 1); locally it makes up as much as 20 percent of the concentrate. Garnet and ilmenite are common in the northern and central parts of the basin. Epidote is virtually absent from concentrates from Buffalo Creek, but staurolite is very common in the southern and southeastern parts of the basin (Overstreet and Griffitts, 1955, fig. 1), where it makes up as much as 20 percent of the concentrate. Throughout most of the basin magnetite is either absent or constitutes only 1–5 percent of the concentrate. Near the mouth of Buffalo Creek, concentrates may contain as much as 40 percent of magnetite. Formerly mined placers on Buffalo Creek and its tributaries were sampled for monazite in 1943 (Lefforge and others, 1944).

Composition of monazite from placers in Buffalo Creek

Analyst: U.S. Geol. Survey in 1945 (Mertie, 1953, p. 7-8, 10, 12) except first entry, which was made by the Dept. Chem. Eng., Tenn. Valley Authority]

Stream	Tenor of riffle gravel (lb of monazite per cu yd)	Composition of monazite (percent)	
		ThO_2	U_3O_8
Buffalo Creek	--------	6.80	------
Buffalo Creek 2.25 miles north of Fallston	6.1	6.46	0.41
Buffalo Creek 1 mile northeast of Fallston	2.9	6.34	.45
Buffalo Creek 1.5 miles southeast of Fallston	2.2	7.38	.31
Long Creek	1.8	6.13	.38
Average	3.2	6.62	.39

The analyzed samples come from parts of the basin in which Toluca Quartz Monzonite is an important source of monazite. Where the source is mostly schist, the amount of thorium oxide in the monazite is less. Thus, monazite from the flood plain at the confluence of Buffalo Creek and the Broad River in Cherokee County, S.C., analyzed by the U.S. Bureau of Mines, contains 4.64 percent of ThO_2 and 0.58 percent of U_3O_8 (Hansen and Theobald, 1955, p. 24).

The amount of monazite in the main valley of Buffalo Creek and its tributaries was estimated by the writer in 1951 to have an average tenor of 0.9 pound per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 711). The greatest resources in monazite and the highest average tenors are in the upper reaches of Buffalo Creek:

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Head of Buffalo Creek east of Toluca and downstream to Glen Creek	2.6	8,200
Glen Creek and major tributary	1.2	2,700
Buffalo Creek from Glen Creek to Little Buffalo Creek	1.8	7,500
Little Buffalo Creek	1.7	6,000
Buffalo Creek from Little Buffalo Creek to Suck Creek	1.2	5,500
Suck Creek	1.4	2,300
Buffalo Creek from Suck Creek to a point 1¼ miles upstream from Muddy Fork	.4	2,900
Buffalo Creek from a point 0.5 mile upstream from Muddy Fork to the Broad River	.2	5,200
Boween River	1.4	4,900
Total	--------	45,200

Flood plains upstream from the junction of Buffalo Creek and Glen Creek were drilled by the U.S. Bureau of Mines in January and February 1952 (Griffith and Overstreet, 1953b, p. 11). Results of the drilling disclosed that this part of the valley contains 2 million cubic yards of alluvium in which there is 1,400 short tons of monazite, 20,000 short tons of garnet, 8,000 short tons of ilmenite, 2,000 short tons of sillimanite and kyanite, 1,000 short tons of rutile, and 200 short tons of zircon (Griffith and Overstreet, 1953b, p. 13). Monazite from this placer contains 6.55 percent of ThO_2 and 0.49 percent of U_3O_8 (Griffith and Overstreet, 1953b, p. 16).

LINCOLN COUNTY AND GASTON COUNTY

The extreme northwestern part of Lincoln County is in the core of the monazite belt, but the rest of the western part of the county as far east as 0.5–2 miles west of the South Fork Catawba River is on the flank of the belt. From 6 to 12 miles east of the South Fork Catawba River, a band of monazite-bearing rocks 2–8 miles wide extends southward across the county (Overstreet, 1962, fig. 2). Concentrates from alluvium in the western part of the county consist of dominant ilmenite, garnet, and monazite with accessory sillimanite, rutile, and zircon, and sparse magnetite and kyanite. In the eastern part of the county, monazite-bearing concentrates from alluvium consist of dominant magnetite, ilmenite, staurolite, and epidote and sparse and local kyanite, hornblende, garnet, and zircon. Most concentrates from the western part of the county contain 5–20 percent of monazite, but those from the eastern part have 5 percent or less.

Both monazite-bearing zones extend southward into Gaston County. The northwestern part of Gaston County is on the southeast flank of the monazite belt and just reaches into the core (Overstreet, 1962, fig. 2). Relations of the monazite-bearing zone in the eastern part of the county are imperfectly known; the zone seems to extend in the direction of the confluence of the South Fork Catawba River with the Catawba River.

Commercial placers were developed along headwater tributaries to Buffalo Creek and Indian Creek in the northwestern part of Lincoln County, and by 1903 (table 58) the output of monazite in the county was a factor, although not a large one, in the production from North Carolina (Pratt, 1905, p. 46; 1907b, p. 122; Sterrett, 1908b, p. 274; Drane and Stuckey, 1925, p. 19; Ladoo, 1925, p. 394; Bryson, 1927, p. 15; Santmyers, 1930, p. 10). The presence of detrital monazite in northwestern Gaston County seems to have been about as well known as the occurrences in Lincoln County, but no records are available to show if monazite was mined. The Cherryville area, however, was cited as a monazite locality (Drane and Stuckey, 1925, p. 19), and the gold placers south of Crowders Mountain were long ago listed as containing monazite (Genth, 1891, p. 77–78, 86). What little formation is available on these occurrences in Gaston County was summarized in the section on "Outlying localities in the Piedmont province between the western and eastern monazite belts."

The only new information on monazite placers in Lincoln County was the appraisal of deposits along Indian Creek, Howards Creek, Pott Creek, and other tributaries to the South Fork Catawba River made in 1952 by A. M. White of the U.S. Geological Survey. He estimated that alluvium in these streams has an average tenor of 0.8 pound of monazite per cubic yard and that the resources are at least 51,500 short tons of monazite (Overstreet, Theobald, and Whitlow, 1959, p. 711). According to A. M. White (written commun., 1954), the tenor of the sediments in the creeks is higher than the tenor of alluvium in the valley of the South Fork Catawba River north of Lincolnton, which is east of the monazite belt:

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Indian Creek	1. 0	16, 000
Howards Creek	1. 3	13, 500
Pott Creek	1. 0	7, 000
South Fork Catawba River	. 5	15, 000
Total	--------	51, 500

UNCONSOLIDATED SEDIMENTARY ROCKS IN THE COASTAL PLAIN PROVINCE

The only report showing distribution of monazite in unconsolidated sediment of the Coastal Plain physiographic province in North Carolina was published by Dryden (1958), and this report is restricted to localities along the inner edge of the province. Dryden (1958, p. 398–400) reported that the results of mineralogical and radiometric studies of 114 concentrates prepared from samples obtained at surface exposures showed that the Coastal Plain formations contained about the same suite of heavy minerals—mainly ilmenite and leucoxene with zircon, rutile, monazite, staurolite, kyanite, sillimanite, tourmaline, and spinel. Locally the formations have as much as 1.81 pounds of monazite per cubic yard, but they average only 0.16 pound per cubic yard. Of the 114 concentrates 14 were barren of monazite, and samples from localities northeast of Fayetteville, Cumberland County, were leaner in monazite than those from localities southwest of Fayetteville (Dryden, 1958, p. 421). Some of the samples having the highest tenor found by Dryden in the Southeastern States came from Cretaceous sedimentary rocks near the inner edge of the Coastal Plain between Fayetteville and the border between North Carolina and South Carolina. Lack of high-tenor samples to the northeast of Fayetteville suggested to Dryden that the eastern monazite belt contributed scant monazite to the Coastal Plain sediments in that area. Samples having a tenor as high as that of samples from southwest of Fayetteville extend into South Carolina.

The Coastal Plain sediments sampled by Dryden ranged in age from Cretaceous to Quaternary. Of the 85 samples taken from the Upper Cretaceous Tuscaloosa Formation, 9 lacked monazite. Two monazite-bearing samples and one monazite-free sample were taken from the Upper Cretaceous Black Creek Formation. Four monazite-bearing samples were taken from the Yorktown Formation of Miocene age. Pleistocene deposits were the source of 22 samples of which 3 lacked monazite. Coastal Plain deposits in North Carolina have not been mined for monazite. The distribution of the monazite-bearing samples is summarized from Dryden (1958, p. 398–400, pl. 19).

TUSCALOOSA FORMATION

The Tuscaloosa Formation is the oldest sedimentary unit of Cretaceous age exposed in North Carolina. It consists of variable tan, red, and gray arkosic sand and interbedded lenticular masses of clay (Stuckey and Conrad, 1958, p. 43–44). These sedimentary materials were derived from the crystalline rocks of the Piedmont and Blue Ridge provinces.

Monazite was found by Dryden in the Tuscaloosa formation at 76 localities in North Carolina (table 72). The most northerly of these occurrences are in Edgecombe County. From there the localities extend southwestward to the State line. With the exception of one sample in the Anderson Creek area of Harnett County and two samples south of Cameron in Moore County, the inferred tenor of all samples was considerably less than 1 pound of monazite per cubic yard.

BLACK CREEK FORMATION

The Upper Cretaceous Black Creek Formation consists of thin-bedded gray to light-yellow sand and dark-gray to black clay in North Carolina (Stuckey and Conrad, 1958, p. 44). The sand is fine to medium grained and generally crossbedded. Monazite was present in samples of sand taken by Dryden (1958, p. 400, pl. 19) at a locality south of Smithfield in Johnston County and at a locality near Purvis in Robeson County. The sand contained 0.16 and 0.14 pound of monazite per cubic yard.

YORKTOWN FORMATION

The Yorktown Formation of late Miocene age in surface exposures in North Carolina consists mostly of clay, sand, and shell marl (Stuckey and Conrad, 1958, p. 45). Arenaceous to calcareous blue clay is the dominant component. Four samples of sand were found by Dryden (1958, p. 400, pl. 19) to be monazite bearing, but the amount of monazite was very small: 0.01 pound per cubic yard near Weldon, Northampton County; 0.03 pound per cubic yard near Rocky Mount, Edgecombe County; 0.07 pound per cubic yard northeast of Wilson, Wilson County; and, 0.03 pound per cubic yard south of Wilson, Wilson County.

PLEISTOCENE DEPOSITS

Nineteen monazite-bearing samples were collected by Dryden (1958, p. 400, pl. 19) from undifferentiated sediments of Pleistocene age in the western part of the Coastal Plain in North Carolina. Eleven of these samples contained more than 0.25 pound of monazite per cubic yard. Inasmuch as only 24 of the 114 samples taken by Dryden from the unconsolidated sediments of that part of the Coastal Plain which is in North Carolina had that much monazite, the Pleistocene sediments seem to have somewhat more monazite than the older formations. The location and tenor of samples from Pleistocene deposits are given in table 73.

STREAM DEPOSITS IN THE COASTAL PLAIN PROVINCE

Alluvium in the valleys of streams in the Coastal

TABLE 72.—*Amount of monazite in the Tuscaloosa Formation in North Carolina*

[Modified from Dryden (1958, p. 398-399, pl. 19]

	Inferred tenor (lb per cu yd)
Edgecombe County:	
East of Rocky Mount	0. 03
	. 05
Wilson County:	
Upper part of Black Creek	. 18
Johnston County:	
Near Pine Level	. 02
South of Smithfield	. 03
West of Smithfield	. 05
	. 08
West of Coats Crossroads	. 01
	. 03
Vicinity of Benson	. 01
	. 12
	. 01
	. 02
Wayne County:	
Near Rose	. 02
	. 05
Harnett County:	
Near Tunington	. 02
	. 03
Near Buies Creek	. 05
	. 4
Northeast of Olivia	. 03
	. 61
Northeast of Spout Springs	. 18
	. 15
Near Anderson Creek	. 23
	. 15
	. 08
	. 03
	. 1
	1. 55
	. 1
Cumberland County:	
Near Linden	. 1
	. 15
Near Wade	. 02
	. 13
West of Wade	. 08
	. 08
Lee County:	
Sanford area	. 05
	. 05
Moore County:	
South of Cameron	1. 81
	. 1
	1. 13
Aberdeen area	. 13
	. 14
	. 06
	. 25
Hoke County:	
Northwest of Timberlake	. 05
	. 1
Raeford area	. 02
	. 25
	. 1
	. 1
Near Pine Bluff	. 2
Richmond County:	
Near Hoffman	. 4
North of Hamlet	. 08
	. 09
	. 1
	. 15
East of Hamlet	. 33
South of Hamlet	. 04
	. 43
Southwest of Hamlet	. 48
	. 05
West of Hamlet	. 33
	. 02
Scotland County:	
Near Silver Hill	. 13
	. 38
	. 15
Near Old Hundred	. 03
	. 18
	. 1
	. 08
	. 1
	. 08
Northeast of Laurinburg	. 04
	. 09
	. 06

TABLE 73.—*Amount of monazite in Pleistocene deposits in North Carolina*

[Modified from Dryden (1958, p. 400, pl. 19)]

	Inferred tenor (lb per cu yd)
Johnston County:	
South of Smithfield	0.09
Benson area	.08
Lee County:	
Sanford area	.12
Moore County:	
Aberdeen area	.25
	.12
	.55
Richmond County:	
Near Hoffman	.29
	.35
North of Hamlet	.38
	.42
	.65
East of Hamlet	.31
Anson County:	
East of Lilesville	.03
Lilesville	.05
Scotland County:	
Near Old Hundred	.25
Southeast of Old Hundred	.02
Near Silver Hill	.19
	.35
	.68

Plain physiographic province of North Carolina has not been mined for monazite, and very few data are available about the tenor of the fluvial sediments. There are no records of reserves. Dryden (1958) gave the only published record of monazite in fluvial deposits in this area, but his report principally refers to surface samples of flood-plain silt or sand, which is ordinarily the lowest tenor material in the sequence of fluvial sediments. He found that concentrates from these materials contained as much as 6 percent of monazite but that the concentrate was small. Concentrates from alluvium in streams rising within the Coastal Plain resemble in mineralogical composition concentrates from Coastal Plain formations. They have a restricted suite of heavy minerals dominated by ilmenite and leucoxene and also contain, in approximate order of abundance, zircon, rutile, monazite, stauroline, kyanite, sillimanite, tourmaline, and spinel. Concentrates from streams rising in the Piedmont were found by Dryden to contain these minerals plus epidote, garnet, and hornblende. Dryden sampled stream and flood-plain deposits at 23 localities in the western part of the Coastal Plain in North Carolina, and he found monazite in 21 of the samples (table 74). Samples having the greatest percentages of monazite are from localities south and southwest of Fayetteville, Cumberland County, in the same general area where the Coastal Plain formations are richest in monazite.

TABLE 74.—*Amount of monazite in concentrates from stream deposits in the coastal plain of North Carolina*

[Modified from Dryden (1958, p. 401, pl. 19)]

County	Description	Percent
Northampton and Halifax	Roanoke River along the county border	0.2
		1.3
		.3
Hertford	Tributary to Meherrin River near Winton	.3
Bertie	Cashie River	.2
Bertie and Martin	Roanoke River along the county border	.3
		.8
Edgecombe	Tar River	1.0
		3.6
		2.1
Wilson	Toisnot Swamp Creek and Contentnea Creek near Wilson.	1.8
		1.0
Wayne	Tributary to Nahunta Swamp Creek near Patetown.	.7
	Neuse River near Goldsboro	.9
Johnston	Neuse River	.2
	Black Creek	1.0
Cumberland	Tributary to Little River	6.0
Hoke	Tributary to Lumber River	.9
Anson	Pee Dee River east of Lilesville	1.5
		.4
Columbus	Lumber River near Boardman	2.5

None of the through-going rivers in the Coastal Plain of North Carolina reach the monazite-rich parts of the monazite belt in the western Piedmont. For this reason the alluvium in their valleys seems to be a much poorer source for monazite than the alluvium in trunk streams in the Coastal Plain of South Carolina below Columbia.

BEACH DEPOSITS

Monazite was reported by Tyler (1934, p. 3–5, 7) as probably present in concentrates from 75 samples of beach sand along the North Carolina coast, but the identification was doubtful. Tyler recognized a persistent suite of heavy minerals consisting of ilmenite, staurolite, epidote, zircon, garnet, sillimanite, kyanite, hornblende, leucoxene, tourmaline, rutile, hypersthene, apatite, magnetite, monazite(?), and andalusite. Staurolite was reported to be the most abundant nonopaque mineral, and the concentrates were said to make up less than 2 percent of the sand. W. H. Jones (1949a, p. 457) stated that monazite is widely distributed in the sand of the North Carolina coast. He estimated that its average abundance is about 2 percent of the heavy minerals in a concentrate and that it varies from 0 to 6 percent of the concentrate (Jones, 1949a, p. 458). An airborne radioactivity survey of the part of the coast of North Carolina south of Cape Fear, Brunswick County, disclosed no unusual radioactivity in the beach sand (Meuschke and others, 1953). This fact indicates that concentrations of monazite in surface sand of the southwestern part of the North Carolina coast are much less than they are in South Carolina, Georgia, and Florida.

Monazite has not been mined from the North Carolina beaches.

OREGON

Monazite has only been reported in fluvial and marine black sands (Dixon, 1926, p. 77–79). A note by Treasher (1940, p. 73a) suggested that it may have been observed locally in gneiss and pegmatite, but detailed work has not disclosed it (Reed and Gilluly, 1932, p. 217). Most of the reported occurrences of detrital monazite in streams are situated in moderately large to very large drainage basins having complex geomorphic histories. The basins are underlain by diverse assemblages of rocks; therefore, unique assignment of sources of the monazite cannot be made. The same difficulty attaches to evaluating the probable sources of the detrital monazite on the Oregon coast. None of these placer deposits was a commercial source of monazite in 1962.

STREAM DEPOSITS

Black sands from streams in eastern Oregon contain small quantities of monazite, garnet, and zircon, but these sands are not sufficiently abundant to be economic sources for monazite (Moore, 1937, p. 7–8). The placers were reported by Moore to occur on pre-Cretaceous formations including siliceous argillites, greenstone, serpentine, other slightly to moderately metamorphosed rocks, gabbro, and granite. For the most part these kinds of rocks in other places in the world are generally barren of or only sparingly contain monazite.

Monazite was observed by Day and Richards (1906b, p. 1206–1215) in black sand from gold placers in streams in northeastern Oregon at Weston, Umatilla County; Wallowa, Wallowa County; and Durkee, Baker County. Mostly the monazite constitutes less than 1 percent of the total heavy minerals in the concentrate, but at Weston it makes up about 2 percent of the material sampled (table 75). In central Oregon a small amount of monazite was found in a platinum-rich concentrate from Antone, Wheeler County. At the mouth of the Hood River and adjacent parts of the Columbia River in Wasco County, northwestern Oregon, fluvial sand contains abundant magnetite and olivine with which there is a very small quantity of monazite. A fraction of a pound of monazite per ton was found in black sands of various origin from the vicinity of Portland and Fulton, Multnomah County; Falls City, Polk County; Morrison and Elk Creek, Lincoln County; and Foster in Linn County. Small amounts of monazite are present in southwestern Oregon in sand from the South Fork Coquille River in Coos County, and in concentrates or sands from Wolf Creek, the Grants Pass area (Butler and Mitchell, 1916, p. 50–51), Kerby, Sucker Creek, and Coyote Creek in Josephine County. A trace of monazite is present in concentrates from Gold Hill and Birdseye Creek, Jackson County. The numerous samples indicate that these Oregon streams are not favorable sources for monazite.

BEACH DEPOSITS

Auriferous and platinum-bearing beach placers were discovered in Oregon in 1852 and were very profitably mined for a while thereafter (Pardee, 1934, p. 4–23). Considerable attention was given to the accessory minerals in these placers about 1905. Industrial minerals like magnetite, chromite, and monazite were found to be present in concentrates and sands from the beaches, raised beaches, and adjacent parts of rivers (Day and Richards, 1906b, p. 1206–1215). Monazite, however, is one of the least common minerals in the placers, and

TABLE 75.—*Mineralogical composition, in pounds per short ton, of natural sand and concentrates from streams in Oregon*

[Modified from Day and Richards (1906, p. 1206–1215). Symbols used: P, present; Tr., trace; --, absent]

Location	Magnetite	Chromite	Ilmenite	Garnet	Olivine	Monazite	Zircon	Quartz	Gold	Platinum	Others	Source
1. Weston, Umatilla County	981	688	--	113	36	46	122	12	P	--	--	Undescribed.
2. Wallowa, Wallowa County	50	9	--	175	--	.7	--	630	P	--	610	Do.
3. Durkee, Baker County	72	2	720	8	--	Tr.	24	518	P	--	656	Do.
4. Do	8	Tr.	32	--	--	Tr.	2	1,450	P	--	506	Do.
5. Antone, Wheeler County	1,762	6	196	--	--	2	--	12	--	P	22	Concentrate.
6. Hood River, Wasco County	995	174	--	221	287	5	16	--	--	--	--	Natural sand.
7. Do	22	3	--	37	118	.4	.4	1,182	P	--	634	Do.
8. Do	30	3	--	9	129	.5	1	1,214	P	--	610	Do.
9. Do	135	19	--	39	339	1	1	1,048	P	--	411	Do.
10. Latourell Falls, Multnomah County	52	312	--	768	360	479	26	--	P	--	--	Undescribed.
11. Portland, Multnomah County	2	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	--	--	--	1,998	Do.
12. Fulton, Multnomah County	830	--	909	--	60	.5	1	79	--	--	118	Natural sand.
13. Falls City, Polk County	217	612	--	739	852	.4	102	40	P	--	1	Undescribed.
14. Morrison, Lincoln County	Tr.	.9	--	3	340	.3	.2	1,383	--	--	272	Natural sand.
15. Do	1	1	--	2	120	.3	.6	1,526	--	--	346	Do.
16. Elk Creek, Lincoln County	2	8	--	16	227	4	1	1,663	P	--	75	Do.
17. Do	.1	2	--	2	207	.4	.4	1,720	P	--	67	Do.
18. Foster, Linn County	1,238	600	--	71	--	.1	.7	10	P	P	--	Do.
19. South Fork Coquille River, Coos County	10	50	--	15	--	.4	12	1,757	--	--	--	Do.
20. Wolf Creek Josephine County	392	90	--	690	31	.1	15	245	P	P	533	Concentrate.
21. Kerby, Josephine County	751	24	--	14	90	24	--	1,405	--	--	483	Natural sand.
22. Do	28	136	56	--	--	Tr.	4	--	P	P	28	Undescribed.
23. Sucker Creek, Josephine County	1,380	392	152	--	--	12	10	2	P	P	48	Concentrate.
24. Coyote Creek, Josephine County	336	1,456	--	--	--	46	28	184	P	P	136	Do.
25. Gold Hill, Jackson County	300	1,100	200	--	--	Tr.	Tr.	--	--	--	400	Do.
26. Birdseye Creek, Jackson County	1,672	8	--	--	--	Tr.	--	--	P	--	200	Do.

it rarely reaches an abundance greater than 1 pound per short ton of concentrate (table 76). Of the 50 monazite-bearing samples described by Day and Richards, those having the most monazite come from the extreme northwest corner of the State in Clatsop County around Astoria, Hammond, Fort Stevens, Clatsop Spit, Clatsop, Clatsop Beach, Warrenton, Gearhart, Gearhart Beach, Gearhart Park, Seaside, and Carnahan Station. Apparently this localization results from the discharge of monazite at the coast by the Columbia River. Among these monazite-bearing samples the richest one, and the richest from Oregon exclusive of the sample reported from the vicinity of Latourell Falls, is a specimen of river bottom sand from the Columbia River near Astoria. Sand and concentrates from the central and southwest coast of Oregon around Yaquina Bay in Lincoln County, the Randolph district in Coos County, and Port Orford and Gold Beach in Curry County generally contain less than 0.1 pound of monazite per short ton. With the possible exception of deposits at the mouth of the Columbia River, the beaches do not contain enough monazite to be a commercial source for the mineral.

PENNSYLVANIA

Monazite in Pennsylvania was first reported in 1899 when J. G. Dailey discovered crystals of the mineral in gneiss of the Wissahickon(?) Formation exposed at a quarry on the southeast side of Chester Creek near Morgan, Aston Township, Delaware County (S. H. Hamilton, 1899, p. 378). The monazite is in crystals as much as 0.25 inch across which are embedded in

TABLE 76.—*Mineralogical composition, in pounds per short ton, of natural sand and concentrates from beaches on the coast of Oregon*

[Modified from analyses by Day and Richards (1906b, p. 1206–1215); P, present]

Location	Source	Magnetite	Chromite	Garnet	Olivine	Monazite	Zircon	Quartz	Gold	Platinum	Others
Clatsop County											
Astoria	Natural sand	11	2	23	50	1	0.6	1,420	P		38
	do	14	6	9	2	Tr.	.2	1,333			632
	do	16	6	8	14	Tr.	.5	1,413			540
	River bottom sand	13	3	271	52	131	.1	639	P		888
Hammond	Natural sand	160	1	65	451	2	1	1,065	P		252
	do	72	7	18	314	1	47	1,193			344
	do	299	22	90	264	1	2	1,073	P	P	247
	do	1,187	145	428	184	1	9	43	P	P	
	do	62	24	30	563	1	.8	1,281	P	P	35
	do	643	171	174		.8	5	335	P	P	524
	do	683	162	226		.9	5	288	P	P	483
	do	666	173	149	218	.4	6	362	P	P	345
Fort Stevens	do	782	195	127		.7	4	237	P	P	365
	do	8	3	6	126	.2	5	1,410	P	P	440
	do	1	1	9	241	.3	4	1,319			422
	do	19	4	83	243	1	2	1,368			277
	do	36	5	11	563	3	1	1,218			161
	do	12	1	3	142	.4	5	1,562	P		272
Clatsop Spit	do	14	1	37	375	.1	.6	1,235			335
	do	3	.6	11	98	.2	.9	993	P		892
	do	53	83	137	466	.6	4	597	P		173
	do	16	2	5	96	.5	.3	1,308	P		570
	do	540	72	143	404	.2	2	670	P		166
Clatsop	do	1	7	9	360	2	2	1,616	P		Tr.
Clatsop Beach	do	537	43	137		.4	.6	54			
Warrenton	do	5	.7	2	461	.8	7	1,455			66
	do	2	1	1	203	.1	.2	1,488	P	P	293
	do	14	2	3	163	.1	.1	1,451	P	P	362
	do	16	5	7	353	1	.8	888	P		725
Between Warrenton and Seaside	do	.3	.3	30	257	.5	.3	1,644			66
Gearhart Beach	do	1	.5	29	11	.1		1,672	P		285
Gearhart Park	do	.1	1	1	49	.4	1	1,650	P		295
	do	1	.1	7	401	1	2	1,555	P		30
Seaside	do	.4	4	22	334	1	1	122	P		408
	do	.8	3	3		1	.5	131	P		1,860
Carnaham Station	do	4	.7	3	381	Tr.	.5	1,609	P	P	1
	do	29	2	155	229	Tr.	.1	1,571	P	P	12
	do	7	2	1	114	Tr.	.1	1,535	P	P	340
	do	.3	.1	1	400	.5	.1	1,460	P		136
	do	2	1	22	210	.5	.3	1,571	P		190
Lincoln County											
Yaquina Bay	do [1]	122	128	516		Tr.	78	256	P		330
	do [2]	86	60	506		Tr.	48	478	P		276
Coos County											
Randolph district	Concentrate panned from beach sand.	11	45	2	.1	1	6	.2	P	P	1,969
	do	22	216	698	219	.2	46	794	P		2
	Natural concentrate(?)	20	583	741		Tr.	45	240			368
	Natural sand	11	202	168	221	Tr.	16	1,378			Tr.
	Concentrate	48	1,500	300		Tr.	100			P	
Curry County											
Port Orford	Undescribed	259	66	1,104	276	.1	3	289			
	do	1.2	Tr.	.6	4	6	Tr.	1,917	P		71
Gold Beach	Natural sand	584	82	205	67	.5	5	524	P	P	529

[1]Contains ilmenite, 572 lb per short ton.
[2]Contains ilmenite, 546 lb per short ton.

flesh-colored orthoclase associated with quartz, green muscovite, ilmenite, magnetite, hematite, hornblende, and tourmaline (Benge and Wherry, 1907, p. 5; Wherry, 1908, p. 70, 77). Feldspar quarries about 0.5 mile to the southwest of Boothwyn, Upper Chichester Township, Delaware County, expose pegmatite which was found in 1906 by Wherry (1908, p. 70–71, 77) to contain monazite, albite, andalusite, beryl, biotite, columbite, almandine, pyrite, muscovite, orthoclase, quartz, sphene, tourmaline, vermiculite, xenotime, and zircon (Benge and Wherry, 1907, p. 6–7; Benge, 1907, p. 45).

The early reports of E. T. Wherry and Elmer Benge pointed out that primary monazite in Pennsylvania is exclusively confined to the areas of highly metamorphosed schist and gneiss and that the monazite is especially plentiful where pegmatite is present in the metamorphic rocks, as in southern Delaware County (Wherry, 1908, p. 60). In a later report Dryden and Dryden (1946, p. 92, 94) described monazite as an accessory mineral in 14 samples of schist from the Wissahickon Formation in southeastern Pennsylvania and northern Maryland. The presence of sillimanite, kyanite, and staurolite in these samples indicates that the monazite came from medium- to high-grade metamorphic rocks. Jaffe, Gottfried, Waring, and Worthing (1959, p. 113) listed three monazite localities in muscovite schist of the Wissahickon Formation in the Philadelphia metropolitan area. The three monazite-bearing exposures are at Crum Creek south of Swathmore, Gulley Run south of West Manayunk, and Darby Creek in Clifton Heights. Alpha activity of about 3,000–4,000 α particles per milligram per hour reported for this monazite indicates a probable ThO_2 content of 4–5 percent. The common presence of sillimanite, fibrolite, and almandine in the schists and gneisses around Philadelphia, as attested by the descriptions of Benge and Wherry (1907) in the Mineral Collector, suggests that a systematic study of the minor heavy accessory minerals would disclose many other monazite localities.

The Keefer Sandstone of Silurian age exposed to the southeast and northeast of Masseyburg, Huntingdon County, was found by Landsberg and Klepper (1939a, p. 8; 1939b, p. 276) to contain abundant accessory zircon and tourmaline accompanied by rutile, hematite, chlorite, muscovite, and monazite. Xenotime but no monazite was observed in the Castanea Sandstone and Tuscarora Quartzite to the northwest of Masseyburg. Xenotime unaccompanied by monazite was also reported for heavy mineral suites from the Monongahela River at East Millsboro and Dunkard Creek in southwestern Pennsylvania (King, 1932, p. 487). The presence of xenotime, however, suggests that monazite may also be present in small amounts (Martens, 1932, p. 73, 79–80).

RHODE ISLAND

CRYSTALLINE ROCKS

As early as 1891 the granites exposed around Westerly and Narragansett Pier, Washington County, were shown by Derby (1891a, p. 205; Am. Naturalist, 1892) to be monazite bearing. The rock at Westerly was said to be especially rich in monazite. Later reports by Kemp (1899, p. 368), Loughlin (1912, p. 127) and Quinn, Jaffe, Smith, and Waring (1957, p. 549) repeated Derby's observation and extended the known presence of monazite in the rocks of the Narragansett Bay area to scattered occurrences in pegmatite dikes that cut across the granite at Westerly. Monazite was reported to occur in granite exposed at the Redstone quarry near Westerly in the Ashaway quadrangle (Jaffe and others, 1959, p. 102). At this locality the monazite is accompanied by bastnaesite and uranoan thorianite, but allanite is absent. The abundances of the accessory minerals in the granite at the Redstone quarry were estimated by Smith and Cisney (1956, p. 80) as percentages of the whole rock:

	Percent
Magnetite and ilmenite	0.13
Apatite	.05
Bastnaesite	.02
Pyrite	.005
Monazite	.002
Sphene	.001
Zircon	.001
Uranoan thorianite	.001

Although allanite was not noted at Redstone quarry, it accompanies monazite in the granite exposed at Narragansett Pier. This granite was said to be equivalent to that in the Redstone quarry near Westerly (Quinn and others, 1957, p. 549).

A dike of granodioritic phase of the Westerly Granite exposed at Bradford, Washington County, contains minor accessory monazite with common accessory allanite, apatite, magnetite, sphene, and zircon (Hall and Eckelmann, 1961, p. 628).

SEDIMENTARY DEPOSITS

Beach sand on the south shore of Block Island, Newport County, in the vicinity of New Shoreham was reported to contain accessory detrital monazite, sillimanite, and zircon (Fisher and Doll, 1927, p. 433). Monazite is present in sedimentary deposits on the Continental Shelf in the Atlantic from Block Island to the 100-fathom line (Alexander, A. E., 1934, p. 13).

SOUTH CAROLINA

Monazite was first found in South Carolina nearly 50 years after its discovery around 1849 in North Carolina. The earliest references to monazite listed by Petty (1950, p. 7–61) in his bibliography of geology of the State were reports by Mezger in 1896 and Nitze in 1897 on monazite placers of the Carolinas, but an even earlier account of monazite from South Carolina is known (Mezger, 1895). By 1900, placers in the western Piedmont in South Carolina were listed in the international literature as commercial sources for monazite (Nordenskiöld, 1900, p. 217), although the first recorded output was 44 short tons in 1903 (table 30). Between 1903 and 1910, the last year of record, the State produced 557 short tons of monazite. By 1917, when the monazite placer industry came to a close in the Carolinas, the distribution of monazite in South Carolina was still not well known (Sloan, 1908, p. 129–142; Atkinson, 1910, p. 77; Pratt, 1916, pl. 1), and it was not until interest in the mineral revived in the 1940's and 1950's that knowledge of its regional distribution became better known than in the descriptions given by Sloan and in the map published by Pratt. Commercial production of monazite from fluvial placers in South Carolina was resumed in 1955 when Marine Minerals, Inc., commenced dredging at Horse Creek, Aiken County. This operation ceased in 1959. Similar placers seem to be present in several other streams in the same general area, and large low-tenor deposits of monazite have been reported on coastal islands southwest of the mouth of the Santee River.

CRYSTALLINE ROCKS IN THE WESTERN MONAZITE BELT IN THE PIEDMONT PROVINCE

The main area in which monazite-bearing crystalline rocks are found in South Carolina is the zone of plutonic gneisses, schists, and granitic rocks in the western part of the Piedmont physiographic province to which Mertie (1953, p. 15) gave the name western monazite belt. As defined by Mertie the western monazite belt in South Carolina is only a segment of a much longer zone which reaches from Alabama to Virginia. Prior to Mertie's work a monazite belt was recognized in the western Piedmont of North and South Carolina, but no extension of the belt was known southwest of Anderson County (Sloan, 1908, p. 129; Pratt, 1916, pl. 1). Thus, most of the South Carolina segment of the western monazite belt was known to Sloan (1908, p. 129), who called it the great economic monazite belt of the Anderson-Spartanburg zone and to Pratt (1916, pl. 1) who called it the monazite belt. The rocks in the western monazite belt in South Carolina are an extension of sillimanite-almandine subfacies schists and gneisses and isofacial sillimanite-free biotitic rocks present in the belt in North Carolina.

Early interpretations ascribe the origin and occurrence of monazite in the crystalline rocks of the western belt in South Carolina to metasomatic processes (Sloan, 1904, p. 140; 1908, p. 130). Later interpretations emphasize the dominance of either relict detrital grains (Mertie, 1953, p. 29–30) or regional metamorphism (Overstreet, Cuppels, and White, 1956) in the occurrence and distribution of the monazite. These concepts are reviewed under the section on "North Carolina" because more work has been done on monazite in that State than in South Carolina.

The known occurrences of monazite in crystalline rocks in the western belt in South Carolina are principally ones described by Mertie (1953). Few other descriptions have been published, but the information available will be summarized. In a later section this information is augmented by descriptions of the distribution of monazite placers in streams in the western monazite belt.

Micaceous schists and feldspathic rocks to the northwest of the Kings Mountain belt in Cherokee County were reported by Sloan (1904, p. 137) to be monazite bearing, but none was known to have mineable concentrations of monazite.

A light-gray medium-grained granitic rock exposed in northeastern Cherokee County, northern Spartanburg County, and central Greenville County was said by Griffitts and Olson (1953b, p. 317) to contain accessory monazite. The rock consists of quartz, microcline, orthoclase, oligoclase, biotite, and muscovite with accessory monazite, apatite, and zircon.

Monazite-bearing rocks were observed at five places in Cherokee County by Mertie (1953, p. 19). These rocks include granite, schist, and pegmatite at three localities near Gaffney; pegmatite exposed 0.9 mile southwest of Grassy Pond; and pegmatite at an exposure 1 mile south of the Cowpens Battleground Monument.

In Spartanburg County pegmatite at a locality 4 miles southeast of Chesnee and granite at exposures 0.3 mile southwest of Mayo, on the north edge of Spartanburg, and 1.9 miles northeast of Reidville have accessory monazite (Mertie, 1953, p. 19–20).

Greenville County was the source of nine monazite-bearing samples of crystalline rocks collected by Mertie (1953, p. 19–20). Gneissic granite at a locality 2.2 miles northeast of Moonville contains accessory monazite. Aplite, pegmatite, and pegmatized gneiss in the vicinity of Conestee have monazite as an accessory mineral as does granite exposed near Piedmont and at two localities near Woodville. Pegmatized gneiss outcropping 3.75 miles south of Batesville and granite gneiss 3.5 miles east-southeast of Simpsonville are also monazite bearing.

Contorted biotite granite gneiss in a quarry 2.4 miles northeast of Liberty, Pickens County, was reported by Alfred and Schroeder (1958, p. 2) to be monazite bearing. According to Alfred and Schroeder, the rock is a dome-shaped intrusive mass of medium-grained layered gneiss in which light-colored bands of feldspar and quartz alternate with thinner and less continuous dark-colored bands rich in biotite. Highly contorted coarse-banded gneiss at the east face of the quarry was said to have more quartz and feldspar and less biotite and accessory minerals than uncontorted close-banded gneiss at the north face (Alfred and Schroeder, 1958, p. 2):

	Percent	
	East face	North face
Quartz	20–25	15–20
Microcline and albite	50–60	40–50
Biotite plus some muscovite	10–15	15–20
Zircon, monazite, garnet, titanite, apatite, pyrite	2–3	3–5

Monazite is not present in every sample of gneiss from the Liberty area, and what was reported as monazite by Alfred and Schroeder may have been epidote; however, nearby epidote-rich low-grade monazite placers indicate the local presence of accessory monazite. J. B. Mertie, Jr. (written commun., 1959) stated that a concentrate of accessory minerals panned from a large sample of weathered rock taken very close to the quarry consisted of 14.3 percent magnetite, 63.8 percent ilmenite, 10.0± percent zircon and epidote, garnet, apatite, sphene, and quartz. Monazite was not present in the concentrate. Mertie also disagreed with Alfred and Schroeder about the composition of the feldspar and the possible origin of the gneiss. He noted that the plagioclase is oligoclase and not albite. In Mertie's opinion the rock is probably a paragneiss instead of an orthogneiss. The probable metasedimentary origin of the gneiss is also supported by H. S. Johnson, Jr. (written commun., 1959).

Granite gneiss and granite at two localities near Honea Path in Anderson County contain accessory monazite (Mertie, 1953, p. 20). Monazite in placers in this area was known at least as early as 1908 (Sloan, 1908, p. 129).

In Laurens County, monazite was found by Mertie (1953, p. 20) in granite gneiss near the Reedy River east of Princeton and in muscovite granite gneiss at the west edge of Gray Court.

OCCURRENCES IN THE CENTRAL PIEDMONT PROVINCE

Detrital monazite in stream sediments was reported at several localities in York County and Union County in the central part of the Piedmont physiographic province in South Carolina. The occurrences are between the western and eastern monazite belts as described by Mertie(1953, pl. 1), and they seem to be a southwestward extension of a small group of monazite localities reported from eastern Gaston County and Mecklenburg County in North Carolina. Together they form a discontinuous but more or less linear and narrow zone that may be related to the distribution of the Yorkville Quartz Monzonite (Overstreet and Bell, 1962, map). This zone has not been given a name, although as early as 1908 Sloan (1908, p. 129) regarded the monazite in York County to be part of a subordinate belt parallel to the main belt of monazite-bearing rocks to the west. Very little is known about the source rocks from which this monazite came, and the Yorkville Quartz Monzonite has not been reported to contain accessory monazite.

In York County monazite has been found as detrital grains in Crowders Creek and its tributaries, and on the north branch of Allison Creek 7 miles northeast of the city of York (Sloan, 1904, p. 140; 1908, p. 129, 141). The Allison Creek deposit, known as the Jessie C. McKinzie placer, was described as being lean in monazite, and the little monazite present was said to be rather localized.

Deposits of monazite sand were reported in Union County, but the location and size have not been described (J. G. Parker, written commun., 1962).

CRYSTALLINE ROCKS IN THE EASTERN MONAZITE BELT IN THE PIEDMONT PROVINCE

As early as 1891 concentrates from granite around Winnsboro in Fairfield County and Newberry in Newberry County had been examined for monazite by Derby (1891a, p. 206). It is not certain from Derby's description that he identified monazite in these rocks; therefore, credit for the discovery belongs to Mertie, who in 1947 found that crystalline rocks in the eastern part of the Piedmont physiographic province in South Carolina were locally monazite bearing. The occurrences were regarded as a possible extension of the eastern monazite belt he recognized in North Carolina and Virginia (Mertie, 1953, pl. 1). Subsequently, crystalline rocks elsewhere in the eastern Piedmont were found by other workers to contain accessory monazite. By 1962, sporadic occurrences of monazite were known from Fairfield County southwestward nearly to the Georgia line. In part the monazite-bearing crystalline rocks are overlapped by the unconsolidated sediments of the Coastal Plain and are exposed in valleys near the inner edge of the Coastal Plain.

The geographic distribution and geologic relations of crystalline rocks with accessory monazite are rather poorly known in the eastern Piedmont. The rocks seem to occupy several subparallel zones instead of one belt, or, possibly, the belt can be interpreted to include all zones. The monazite-bearing rocks occur in areas where the regional metamorphism reaches the kyanite-staurolite subfacies. The eastern belt is separated from the western belt by albite-epidote-amphibolite facies and lower grade rocks in the central Piedmont (Overstreet, Overstreet, and Bell, 1960; Overstreet and Bell, 1962). The eastern belt is of lower average metamorphic grade than the western belt, and it seems to contain more postkinematic granitic intrusive rocks with accessory monazite than the western belt. Possibly the subparallel zones where monazite is found in the eastern belt represent local metamorphic highs in an otherwise monazite-free area.

The localities where monazite was first discovered in the eastern belt are the quarries southwest and west of Winnsboro in Fairfield County. Mertie found monazite in four samples of postkinematic granite exposed at Rion and Anderson Quarry southwest of Winnsboro and in one sample of granite from a quarry at Blairs to the west of Winnsboro (Mertie, 1953, p. 20). The granite mass at Winnsboro was later shown to be a teardrop-shaped diapiric postkinematic pluton of probable late Paleozoic age that intruded kyanite-staurolite subfacies schists (Overstreet, Overstreet, and Bell, 1960; Overstreet and Bell, 1962; Overstreet, Bell and others, 1961, p. B105). The granite is much younger than the main monazite-bearing granitic rocks in the western belt, which are probably Ordovician in age. The monazite-bearing granite at Blairs may also be late Paleozoic in age. As yet the age of maximum metamorphism of the schists and gneisses in Fairfield County is not known, but it may be only a little older than the diapiric pluton and considerably younger than the Ordovician metamorphic climax recorded in the western belt. The eastern monazite belt is probably younger than the western belt in the Piedmont and is certainly younger than the belt in the Blue Ridge. Genetic implications following from the probability that the monazite belts are progressively younger from west to east have been discussed in the section on North Carolina.

Accessory monazite was reported by J. F. McCauley (oral commun., 1959) in thin sections of granite and gneiss from central and eastern Newberry County to the west-southwest of the occurrences in Fairfield County. Inasmuch as monazite is not usually observed in thin sections of monazite-bearing rocks from the Southeastern States because it is ordinarily extremely sparse, these observations suggest that some rocks in Newberry County may have accessory monazite in more than the usual amount.

Deep red soil on the campus of the University of South Carolina in Columbia, Richland County, was reported to contain sparse monazite (Perry, 1957, p. 5), but it is not certain if the monazite is residual from underlying crystalline rocks or if it was brought in along ancient water courses from the northwest.

Radioactive granite underlying the Tuscaloosa Formation in the valley of Long Creek, a tributary to Twelvemile Creek in Lexington County, is probably monazite bearing (Schmidt, 1962, p. 36). Similar radioactive granite exposed in the valley of McTier Creek in northern Aiken County contains monazite (H. S. Johnson, Jr., oral commun., 1959; Schmidt, 1962, p. 35). Radioactive granite in the vicinity of Graniteville, Aiken County, is probably monazite bearing (Schmidt, 1962, p. 36).

FLUVIAL PLACERS IN THE WESTERN PIEDMONT PROVINCE

Small fluvial placers formed on monazite-bearing crystalline rocks in the western Piedmont physiographic province of South Carolina were the source of 557 short tons of monazite produced by hand methods of mining between 1903 and 1910 (table 30). Most of the mining was done in Cherokee County north and west of Gaffney, Spartanburg County near the settlement of Cowpens, Greenville County in the vicinity of Mauldin and Piedmont, and Anderson County at Pelzer (Pratt, 1903, p. 180–181; 1906, p. 1314; 1907a, p. 38; Eng. and Mining Jour., 1906b; Böhm, 1906; Graton, 1906, p. 116–117; Sloan, 1908, p. 131; Ladoo, 1925, p. 396; Santmyers, 1930, p. 10). The mining of South Carolina placers ceased in 1910 after the monazite discovered in India was entered into world commerce at a much lower price than could be met by South Carolina mines (Schaller, 1919, p. 156). In 1906 monazite placers were discovered in parts of Pickens, Oconee, and Laurens Counties, but none seems to have been mined before the industry closed (Pratt, 1907b, p. 109; Pratt and Sterrett, 1908a, p. 315; Sterrett, 1908b, p. 274). Names and locations of 39 individual placers in the western monazite belt in South Carolina were listed by Sloan (1908, p. 132–142) near the close of monazite mining:

Cherokee County

1. W. H. Weber placer on Thicketty Creek 2.5 miles northeast of the settlement of Cowpens in Spartanburg County.
2. J. Caldwell and Romeo Martin mine on Thicketty Creek 2.4 miles northeast of Cowpens.
3. James Oglesby placer on Thicketty Creek 1 mile northeast of Cowpens.
4. R. Potter placer on east side of Thicketty Creek north of Thicketty.
5. Placer along Littlejohn Creek on the property of Joe Husky, J. C. Blanton, J. C. Painter, and T. T. McGraw between 3 and 4 miles northwest of Gaffney.

6. Frank Leadford placer on Ashworth Creek.
7. Placer on the Serratt property and J. B. Jones land along the east bank of Cherokee Creek 3.5 miles north of Gaffney
8. J. J. Magnus and J. M. Swaford placer on the east bank of Cherokee Creek 3.5 miles north of Gaffney.
9. Lemon mine on a northwest tributary to Cherokee Creek 3.3 miles north of Gaffney.

Spartanburg County

10. Paine's placer 3 miles south of Greer.
11. A tributary to the Pacolet River 2.5 miles east of Spartanburg.
12. J. J. C. Ezell placer 8 miles north of Cowpens.
13. Martin's placer on a tributary to the Pacolet River 5 miles northwest of Cowpens.
14. Conway Black placer 2.5 miles north of Converse.
15. Charles Petty placer 4 miles northwest of Cowpens.
16. J. Dewberry placer 4 miles northwest of Cowpens.
17. W. E. Bryant mine on Becks Branch tributary to the Pacolet River 0.5 mile northwest of Cowpens.
18. Placer on the property of Charles Sims, Rufe Tanner, S. B. Wilkins, and T. E. Wilkins along Becks Branch 0.5 mile west of Cowpens.
19. Robins placer 3 miles north of Cowpens.
20. Martin mine on Allen Creek 8 miles north of Pacolet.
21. J. M. Hays placer on a branch of Allen Creek 8 miles north of Pacolet.
22. J. V. Welchel mine on Floods Branch, a tributary to Allen Creek, 0.7 mile north of Cowpens.
23. J. Duval mine on Island Creek, a fork of Allen Creek.

Greenville County

24. J. D. Green placer on Five Mile Branch tributary to Gilder Creek 6 miles east of Greenville and immediately south of Roper Mountain. Downstream along Five Mile Branch and Gilder Creek, placer monazite is present on property of Jackson Brown, Thomas Bramlet, Louis Rector, A. Rothschild, and Wyatt Smith.
25. Alexander brothers' placer 4 miles west of Mauldin.
26. Berry Waldrop placer on Baker Creek 5.5 miles south of Piedmont.
27. Dave Terry placer 6 miles south of Piedmont.
28. J. S. Hill, Jr., placer 0.4 mile west of Mauldin.
29. Thomas Fowler placer on Maple Creek 1 mile south of Mauldin.
30. A. White placer 1 mile south of Mauldin.
31. Molly Garrett placer on Maple Creek 1.2 miles south of Mauldin.
32. Brooks mine on Maple Creek 1.4 miles southwest of Mauldin.
33. J. R. Bramlet placer 1.4 miles southwest of Mauldin.
34. Wyatt Smith placer on Gilder Creek 1.2 miles northeast of Mauldin.
35. W. M. Burdin mine 3 miles southeast of Mauldin.
36. F. A. Alston mine 2.5 miles southeast of Mauldin.

Anderson County

37. Robert Simpson placer 3.5 miles north-northwest of Pelzer.
38. J. G. S. Smalls placer 1 mile south of Pelzer.
39. Charles Wideman placer 1 mile south of Pelzer.

Several of these deposits were cited in earlier reports than Sloan's, and they have been mentioned time and again in later discussion, with the result that the apparent importance of individual small placers has been magnified out of regional perspective. Even the Lemon mine, called one of the most continuous and prolific producers of monazite in South Carolina, was only a small operation situated on a little tributary to Cherokee Creek (Sloan, 1908, p. 140). As early reports show, the mined placers were small and shallow, with monazite-bearing gravel generally less than 1 foot thick (Graton, 1906, p. 117). The thickness of overburden that could be profitably removed during mining varied with the richness of the gravel, but no worked deposit was more than 10 feet deep, a few hundred feet wide, and a mile long (Sterrett, 1908b, p. 279–280). The main valleys of large streams in the monazite belt were not mined.

In addition to the deposits listed above the early literature called attention to monazite placers on a tributary to the Saluda River 1 mile east of Donalds in Abbeville County and on Walnut Creek near Ware Shoals in Greenwood County (Sloan, 1908, p. 129).

Monazite from South Carolina placers was said by Sloan (p. 131) to contain 3–7.25 percent of ThO_2, but only a single analysis was recorded in the early literature. It was made in 1908 by Chernik and has since been republished by Houk (1946, p. 3):

	Percent
Ce_2O_3	34. 50
$(La, Di, Y)_2O_3$	28. 80
ThO_2	7. 00
P_2O_5	26. 00
SiO_2	2. 00
TiO_2	. 90
ZrO_2	. 70
CaO	. 70
Total	100. 60

For 30 years after the close of the monazite industry in South Carolina in 1910, no studies of fluvial monazite placers were undertaken. In 1943 the Regional Products Research Division of the Tennessee Valley Authority examined stream placers in Cherokee County to learn if these sources could be substituted for foreign supplies of monazite (McDaniel, 1943, p. unnumbered). Special circumstances of unusually high price and demand would be needed to revive the industry. If such conditions were met, the Carolina deposits would probably be sufficient to supply moderate domestic needs.

During 1945 Mertie (1953, p. 9, 12) panned concentrates from gravel in small streams at 11 localities in Cherokee County, 1 in Spartanburg County, and 4 in Greenville County. The amount of monazite in the riffle gravel was estimated, and monazite separated from the concentrates was analyzed for ThO_2 and U_3O_8 (table 77).

The range and average amounts of monazite in the riffle gravel confirmed earlier reports of the tenor of monazite-bearing gravel in South Carolina; for example, Sloan (1908, p. 131) had reported that "with a full supply of water a placer deposit which will afford a pound of monazite from a barrow-load of gravel is considered a 'good proposition.'" If the barrow-load were assumed to be about 2.5 cubic feet, then the gravel would have contained about 10 pounds of monazite to the cubic yard. The tenor of the sediment from grass roots to bedrock was, of course, much less, but then only gravel was mined and low-tenor overburden was discarded.

TABLE 77.—*Thorium and rare-earth composition of monazite in riffle gravel from Cherokee, Spartanburg, and Greenville Counties, S.C.*

[Modified from Mertie (1953, p. 9–10, 12). Chemical analyses for ThO_2 and U_3O_8 by F. S. Grimaldi, U.S. Geol. Survey]

Sample	Location	Tenor of gravel (lb of monazite per cu yd)	Composition of monazite (percent)	
			ThO_2	U_3O_8
	Cherokee County:			
45-Mt-65	Cherokee Creek	1.4	5.87	0.49
36	do	1.8	6.45	.23
38	do	3.5	6.21	.22
29	Little Cherokee Creek	3.1	4.90	.45
40	Beaverdam Creek	1.2	5.91	.22
60	Joe Welchell Creek	3.6	6.44	.24
50	Floyd Branch, Island Creek	3.1	4.95	.55
55	Cudds Creek	7.9	4.84	.58
59	Bill Martin Creek	6.4	4.91	.58
74	Little Thicketty Creek	3.9	6.59	.19
73	Macedonia Creek	7.3	6.76	.18
	Spartanburg County:			
66	Double Branch	1.7	5.47	.36
	Greenville County:			
98	Gilder Creek	3.8	5.56	.55
101	Reedy Creek	3.8	5.05	.47
81	Huff Creek	8.6	5.08	.24
105	do	41.9	4.85	.32
Average		6.4	5.61	.36

A concentrate from monazite-bearing sand was collected by A. S. Furcron from the South Carolina side of the Tugaloo River in Oconee County below the mouth of the Chauga River (Zodac, 1953, p. 58). The concentrate contained monazite, zircon, garnet, rutile, epidote, and magnetite.

A regional appraisal of fluvial placers downstream from the former sites of mining in the western Piedmont was undertaken by the U.S. Geological Survey in 1951 for the Atomic Energy Commission as a result of Mertie's investigations. Selected valleys were drilled by the U.S. Bureau of Mines. Fieldwork was completed in 1954. Results of these investigations showed that large valleys in the western monazite belt in South Carolina contain at least 367,000 short tons of monazite in sediments having an average tenor of 0.6 pound of monazite per cubic yard from the top of the flood plain to bedrock (Overstreet, Theobald, and Whitlow, 1959, p. 710–712). The work also showed that the richest deposits are in streams that flow on a zone of sillimanite schists and gneisses which form the core of the monazite belt (Overstreet, Cuppels, and White, 1956; Overstreet, 1962, p. 158–161). Summaries of this exploration follow and are given in geographic order by county from northeast to southwest.

CHEROKEE COUNTY

The east edge of the monazite belt passes southwestward across Cherokee County about 3 miles east of Gaffney dividing the county into a monazite-bearing northwest half and a monazite-free southeast half (Keith and Sterrett, 1931, map; Mertie, 1953, pl. 1; Overstreet, 1962, fig. 2). The northwest quarter of the county is in the core of the monazite belt, and from a point about 3 miles northwest of Gaffney to the extreme northwest corner of the county, concentrates from stream sediments contain 15–50 percent of monazite, with most concentrates having about 20–30 percent. Rutile, sillimanite, almandine, and ilmenite are the principal associated minerals. Along the east edge of the belt near Gaffney and east of the belt in monazite-free parts of the county, staurolite, kyanite, magnetite, and amphibole dominate the concentrate (Overstreet and Griffitts, 1955, pl. 1).

The monazite-bearing streams in the county are tributaries to the Broad River. Along the north edge of the county several short but monazite-rich streams rise and flow northward to enter the Broad River in Cleveland County and Rutherford County, N.C. Several of these short north-flowing tributaries to the Broad River were former sites of monazite placer mines. Near the State line the trend of the valley of the Broad River swings from east to south, and short tributaries in the belt north of Gaffney flow east to the river. One major south-flowing monazite-bearing tributary enters the Broad River from the north in northeastern Cherokee County. This is Buffalo Creek. Except for the short north-flowing and east-flowing creeks, the principal drainage in the northwest half of Cherokee County is the basin of Cherokee Creek and that of Thicketty Creek. Both these streams enter the Broad River from the west. The resources in monazite in fluvial deposits along the short north-flowing and east-flowing tributaries to the Broad River, including their parts in North Carolina, the Broad River itself, including the east-flowing segment in North Carolina from a point near the northwest corner of Cherokee County to the State line north of Gaffney and the south-flowing segment from the State line to a point about a mile upstream from the mouth of Cherokee Creek, and the drainage basins of Cherokee and Thicketty Creek were estimated to be at least 70,000 short tons (Overstreet, Theobald, and Whitlow, 1959, p. 711).

The resources of monazite in the main valley of the Broad River from the point in North Carolina north of the northwest corner of Cherokee County to the point in South Carolina upstream from Cherokee Creek was conservatively estimated to be at least 17,000 short tons in 90 million cubic yards of alluvium (Overstreet, Theobald, and Whitlow, 1959, p. 711).

The reserves of monazite in the valley of the Broad River at the mouth of Buffalo Creek were evaluated by churn drilling and estimated to be 3,500 short tons (Hansen and Theobald, 1955, p. 5). Above its junction with Buffalo Creek, the Broad River emerges at the east side of the monazite belt. Its many tributaries in the belt drain about 1,400 square miles underlain by weathered monazite-bearing crystalline rocks and give the river the maximum input of monazite of any trunk stream crossing the western belt. Buffalo Creek rises in northwestern Lincoln County, N.C., and flows southward for 43 miles to join the Broad River in northeastern Cherokee County, S.C. In the lower half of Buffalo Creek, only its western tributaries reach monazite-bearing rocks, but the upper half of the creek is in or along the east edge of the monazite belt. The flood plain in the valley of the Broad River at the mouth of Buffalo Creek was drilled by the U.S. Bureau of Mines in November 1952 to determine the tenor and composition of sediments in the valley of a trunk stream crossing the belt. Results of this work in South Carolina are summarized in the following discussion; a review of Buffalo Creek as a whole was given in the section on North Carolina.

Eight churn-drill holes were sunk in the flood plain on the Broad River, and two were sunk in the flood plain at the lower end of Buffalo Creek. The alluvium was found to range in depth from 13 feet on Buffalo Creek to 26.5 feet on the Broad River. The combined area of the deposit was 2,760,000 square yards, and the volume of alluvium was estimated to be 19.7 million cubic yards. Most of the alluvium was clay, silt, and fine sand, and its tenor in heavy minerals and monazite was found to be low: 4.86–20.51 pounds of black sand per cubic yard, the average being 11.8 pounds, and 0.16–0.62 pound of monazite per cubic yard, the average being 0.36 pound (Hansen and Theobald, 1955, p. 21, 24–25). The mineralogical composition of a concentrate from a composite sample from one drill hole in the flood plain of the Broad River was reported to be (Hansen and Theobald, 1955, p. 18) as follows:

	Percent of concentrate		*Percent of concentrate*
Ilmenite	40	Rutile	3.0
Epidote	13	Kyanite and sillimanite	2.0
Zircon	13	Magnetite	1.5
Garnet	10	Staurolite	1±
Quartz	7	Tourmaline	1±
Amphibole	6	Xenotime	Trace
Monazite	3.3		

Unless a part of the valley of this trunk stream could be found that is filled with deposits containing far more coarse-grained sediment than was found on this part of the Broad River, workable monazite placers cannot be expected. Monazite from the flood plain on the Broad River at the mouth of Buffalo Creek contains 4.64 percent of ThO_2 and 0.58 percent of U_3O_8 (Hansen and Theobald, 1955, p. 24).

The main short north-flowing tributaries that rise in northern Cherokee County, S.C., and enter the Broad River in Rutherford County and Cleveland County, N.C., are, from west to east, Horse Creek, Suck Creek, Ashworth Creek, and Camp Creek. The tenor and resources of monazite along these streams were estimated by P. K. Theobald, Jr. (written commun., 1954) of the U.S. Geological Survey:

	Tenor (lb of monazite per cu yd)	*Resources (short tons)*
Horse Creek	2.3	4,100
Suck Creek	1.3	3,300
Ashworth Creek	3.1	3,900
Camp Creek	.1	40

Ashworth Creek was worked for monazite at the Frank Leadford placer (as noted on p. 235), and the southeastern headwaters of Camp Creek were also mined (Keith and Sterrett, 1931, map).

Ross Creek and its main tributary, Sarratt Creek, are the principal eastward-flowing monazite-bearing streams to enter the Broad River in Cherokee County. Parts of the headwaters of both streams were formerly mined for monazite (Keith and Sterrett, 1931, map). The valleys of the two creeks were estimated by P. K. Theobald, Jr. (written commun., 1954) to contain at least 3,800 short tons of monazite in alluvium having an average tenor of 1.4 pounds of monazite per cubic yard.

Cherokee Creek is mostly underlain by granitic and high-rank metamorphic rocks in the central and eastern parts of the monazite belt (P. K. Theobald, Jr., written commun., 1954). Only the lower 1.5–2 miles of its course is east of the monazite belt. Many of its headwater tributaries, particularly branches in the vicinity of Grassy Pond, were formerly mined for monazite (p. 235) (Keith and Sterrett, 1931, map). Resources of monazite in the stream as a whole were estimated by P. K. Theobald, Jr. (written commun., 1954) to be 9,000 short tons in sediments having an average tenor of 1.5 pounds of monazite per cubic yard.

Thicketty Creek drains the southwest half of Cherokee County, but only the upstream half of the creek is underlain by monazite-bearing rocks (P. K. Theobald, Jr., written commun., 1954). In that part of Thicketty Creek the tenor of samples of riffle gravel was found to range from 0.1 to 8.6 pounds of monazite per cubic yard. High-tenor gravel was formerly mined for monazite at many places on small tributaries to Thicketty Creek (p. 234–235), particularly between Gaffney in Cherokee County and the settlement of Cowpens in Spartanburg County (Keith and Sterrett, 1931, map). Resources of monazite in the upstream half of Thicketty Creek were estimated by Theobald to be 27,000 short tons in alluvium having an average tenor from grass roots to bedrock of 0.9 pound of monazite per cubic yard.

A very large flood plain occupies the valley of Thicketty Creek upstream and down from the confluence with Little Thicketty Creek. The junction of the streams is a few miles downstream from the east edge of the monazite belt. Above the junction, Thicketty Creek drains an area of 40 square miles underlain by monazite-bearing schist, gneiss, and granite, and Little Thicketty Creek drains an area of 20 square miles underlain by similar rocks. At the junction, and downstream from it, monazite-free schists occur; some are kyanitic or staurolitic, and others are chlorite bearing. A line of eight churn-drill holes was sunk by the U.S. Bureau of Mines across the large flood plain at the confluence of the two streams to appraise it as a source for detrital monazite (Hansen and Theobald, 1955, p. 11–19). The area drilled covers a little more than 3 million square yards, and the thickness of alluvium ranged from 14 to 22.5 feet.

Most of the alluvium is very fine grained and consists of a mixture of clay and silt deposited during successive periods of overbank flooding. Each layer of clay and silt and underlying fine sand represents part of the suspended load of the flood-stage stream. These suspended-load deposits proved to be lean in heavy minerals. They overlie relatively thin layers of coarse sand and gravel deposited from the bedload. The bedload deposits contain most of the monazite (table 78). The dominance of fine-grained sediments in this flood plain reflects the mode of accumulation from overbank floods and the thoroughly weathered condition of the crystalline rocks in the drainage basins. This dominance of fine-grained sediments also results in a low average tenor of 14.5 pounds of black sand and 0.41 pound of monazite per cubic yard (Hansen and Theobald, 1955, p. 25). Reserves in this flood plain were estimated to be 4,300 short tons of monazite.

TABLE 78.—*Amount of monazite related to class of sediment in the flood plain at the junction of Thicketty Creek and Little Thicketty Creek in Cherokee County, S.C.*

[Modified from Hansen and Theobald (1955, p. 15, table 2)]

Size grade of sediment	Thickness [1]		Tenor (lb per cu yd)	
	Feet	Percent of total thickness	Black sand	Monazite
Silt, red to brown	3–5	19–36	0.27–20.85	0.01–0.40
Clay, gray, and fine sand	0–11.5	0–55	.0 –19.80	.00– .44
Fine sand	0–5	0–36	.0 –30.34	.00– .76
Coarse sand and gravel	4–13	21–81	10.43–67.01	.54–2.24

[1] Based on 8 holes drilled through flood-plain sediments 14–22.5 ft thick.

A concentrate prepared from a composite sample from one drill hole on Thicketty Creek was reported to have the following composition (Hansen and Theobald, 1955, table 3, p. 18):

	Percent		Percent
Ilmenite	42	Kyanite and sillimanite	11
Epidote	3	Magnetite	1
Zircon	.3	Staurolite	.1
Garnet	11	Xenotime	.7
Quartz	16	Spodumene	.5
Amphibole	3	Columbite	.1
Monazite	5.2	Uraninite	Trace
Rutile	4.2		

The presence of spodumene and columbite in the concentrate suggests that small displays of the type of tin-spodumene pegmatite exploited for spodumene near Kings Mountain in Cleveland County, N.C., and as yet unrecognized in the drainage basin of Thicketty Creek, may be present in this part of Cherokee County. Monazite from the flood plain at the confluence of Thicketty Creek and Little Thicketty Creek contains 5.93 percent of ThO_2 and 0.50 percent of U_3O_8 (Hansen and Theobald, 1955, p. 24).

SPARTANBURG COUNTY

The northwestern part of the high-tenor core of the monazite belt enters the north edge of Spartanburg County about 10 miles west of the Cherokee County line. The southeastern part enters from Cherokee County about 4 miles south of a line between the towns of Gaffney and Spartanburg. Thus, in the northeastern part of Spartanburg County the core of the belt is about 20 miles wide. As it passes southwestward across Spartanburg County it narrows to a width of 6 miles at the junction of the North Tyger River and Middle Tyger River. Within a matter of a few miles, however, the northwest side of the core of the belt expands abruptly toward the northwest along the divide between the Middle Tyger River and South Tyger River and enters Greenville County along the valley of the South Tyger River. The southeast side of the core of the belt persists in a fairly straight southwest-trending line and leaves Spartanburg County at the Enoree River about 2 miles downstream from the Laurens County line (Overstreet, 1962, fig. 2). The width of the core of the belt where it leaves the county is about the same as where it enters; however, concentrates from alluvium in the core of the belt in the southwestern part of the county generally contain from 10 to 20 percent of monazite, whereas concentrates from alluvium in the core of the belt in the central and northeastern parts of the county contain from 10 to 30 percent of monazite. Concentrates from northwestern Spartanburg County generally have only 1–5 percent of monazite. Most streams in the southeastern part of the county, except in the vicinity of the junction of the North Tyger River and South Tyger River, are barren of monazite.

Rutile in low percentages is associated with monazite in concentrates from alluvium in the northeastern part of the county. Its presence in this area is an extension of the prominent rutile-bearing area in central Cherokee County. Rutile is generally absent from concentrates in the middle part of Spartanburg County where the monazite-rich core of the belt narrows. Rutile again enters concentrates in two zones in the western and southwestern parts of the county: one zone about 5 miles wide, where concentrates from alluvium contain rutile, extends westward into Greenville County along the South Tyger River; the other zone is about 12 miles wide and extends southwestward out of Spartanburg County along the line between Greenville County and Laurens County. Both are in the monazite-rich core of the belt, and the more northerly zone is associated with abundant sillimanite.

Sillimanite is common in amounts between 1 and 5 percent of the concentrate in the monazite-rich northeastern part of the county. Where the core of the monazite belt narrows near the junction of the North Tyger River and Middle Tyger River, sillimanite is absent from concentrates, but along the divide between the Middle Tyger River and the South Tyger River a broad zone forms, in which concentrates again contain sillimanite. This zone extends westward into Greenville County and corresponds to the westward extension of the wide part of the core of the monazite belt. The southeast edge of this zone of sillimanite-bearing concentrates, however, does not reach the southeast limit of monazite-rich concentrates, which is 4 miles farther to the east (Overstreet, 1962, fig. 2).

Almandine and ilmenite are common associates of monazite, sillimanite, and rutile in the core of the monazite belt in Spartanburg County. Almandine is most abundant in the northeastern and southwestern parts of the county where the highest percentages of monazite are present in concentrates from alluvium. From 5 to 20 percent of almandine is commonly present in concentrates from the core of the belt, but monazite-free concentrates to the northwest and southeast of the belt lack almandine. Throughout the core of the belt in Spartanburg County concentrates have from 40 to 60 percent of ilmenite.

Epidote and magnetite are virtually absent from the core of the monazite belt in Spartanburg County, but both appear along the flanks of the belt and are the dominant minerals in concentrates from the northwest side of the core of the belt upstream from the confluence of the North Tyger River and Middle Tyger River.

Monazite placers in Spartanburg County were appraised in 1952 by N. P. Cuppels (written commun., 1954), and summaries of the results have been published (Overstreet, Cuppels, and White, 1956; Overstreet, Theobald, and Whitlow, 1959, p. 710). The summaries show that monazite-bearing tributaries to the Pacolet River in Spartanburg County contain at least 79,000 short tons of monazite, and monazite-bearing tributaries to the Tyger River in the county contain at least 44,000 short tons of monazite. The average tenor of alluvial sediments in the basin of the Pacolet River is 0.8 pound of monazite per cubic yard, but the average tenor of sediments along streams in the Tyger River basin is only 0.4 pound per cubic yard. This reflects the narrow width of the monazite-rich core of the belt in the Tyger River basin. Two monazite placers formerly mined in Spartanburg County are in the drainage basin of the Pacolet River and one, the Paine placer, is in the basin of the Enoree River (p. 235). Short south-flowing tributaries to the Enoree River in Spartanburg County were appraised by Cuppels together with the much longer east-flowing tributaries in Greenville County and Laurens County. The short streams entering the Enoree in Spartanburg County are discussed under Greenville County and Laurens County.

The North Pacolet River and South Pacolet River and their tributaries upstream from their confluence drain a little more than 200 square miles in the northern part of Spartanburg County toward the west side of the monazite belt (N. P. Cuppels, written commun., 1954). Most concentrates contain between 1 and 5 percent of monazite, but the average tenor of the alluvium is only 0.4 pound of monazite per cubic yard, and the resources were estimated to be 14,000 short tons of monazite. The average tenor and resources in the principal creeks in the area were inferred:

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Part of North Pacolet River	0.1	700
Obed Creek	.9	1, 500
Bird Creek	.4	400
Wood Branch	.5	700
Part of South Pacolet River	.4	9, 500
Other streams	(1)	1, 200

[1] Not reported.

Downstream from the junction of the North Pacolet River and the South Pacolet River, the stream is known as the Pacolet River. It crosses the core of the monazite belt and emerges on the east side. Within the belt the principal tributary of Pacolet River is Buck Creek. Immediately southeast of the belt the Pacolet River is joined from the south by a long stream, Lawson Fork Creek, which also drains the core of the monazite belt.

Alluvium on Buck Creek and nearby tributaries to the Pacolet River, including flood plains along the Pacolet, was estimated by N. P. Cuppels (written commun., 1954; Overstreet, Theobald, and Whitlow, 1959, p. 710) to contain 48,000 short tons of monazite and to have an average tenor of 1.4 pounds of monazite per cubic yard. Estimated average tenors and resources in monazite along the main creeks in the area were reported:

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Buck Creek	1. 9	16, 500
Casey Creek	1. 8	2, 400
Cherokee Creek	2. 1	3, 300
Island Creek	1. 7	4, 300
Pole Ridge Creek	5. 1	3, 200
Peters Creek	2. 4	6, 000
Part of Pacolet River	. 6	11, 000
Other streams	(1)	1, 300

[1] Not reported.

The Ezell placer mentioned listed on page 235 is on a tributary to Buck Creek.

Four holes were drilled by the U.S. Bureau of Mines during January 1953 on the flood plain of the Pacolet River at a point about 6 miles northeast of Spartanburg (Hansen and Cuppels, 1955, p. 21–22). The alluvium averaged 22 feet in depth and consisted chiefly of sand. Samples from the four holes were found to contain an average of 19 pounds of black sand per cubic yard, of which 7–8 pounds was ilmenite, 0.57 pound was monazite, 0.5 pound was rutile, and 0.57 pound was zircon.

Alluvium along Lawson Fork Creek and its main tributaries was estimated by N. P. Cuppels to contain at least 17,000 short tons of monazite and to have an average tenor of 0.7 pound per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). Estimated average tenors and resources in monazite in flood plains on Lawson Fork Creek and other streams in its drainage basin were reported to be as follows (N. P. Cuppels, written commun., 1954):

	Average tenor (lb of monazite per cu yd)	*Resources (short tons)*
Meadow Creek	0. 3	600
Green Creek	. 7	1, 000
Shoally Creek	1. 0	1, 500
Lawson Fork Creek	. 8	13, 900

An area of about 400 square miles in the monazite belt is drained by the North Tyger River and South Tyger River in Spartanburg County. The southeast edge of the core of the belt is about 8 miles upstream from the junction of the rivers, but sparse monazite is found in tributaries as far southeast as the confluence (Overstreet, 1962, fig. 2). The best placers are in streams at the core of the belt, but the core is narrow and few large or rich placers are present. Monazite-bearing alluvium occurs along Beaverdam Creek and other tributaries to Fairforest Creek, in minor tributaries to parts of North Tyger River, Middle Tyger River, and South Tyger River, at the junction of North Tyger River and Middle Tyger River, and along Ferguson Creek and other streams entering the South Tyger River.

Beaverdam Creek and other tributaries to Fairforest Creek were estimated by N. P. Cuppels to contain at least 7,900 short tons of monazite in alluvium having an average tenor of 0.5 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). Sediment having the greatest tenor in monazite in the drainage basin was found in streams draining the divide north of Beaverdam Creek near the Spartanburg Airport. Small areas of alluvium containing as much as 9.6 pounds of monazite per cubic yard were found in this area; however, the best placer observed was a part of the flood plain in the valley of Fairforest Creek between Arcadia and the mouth of Beaverdam Creek. In this long valley the flood-plain sediments have an average tenor of 0.7 pound of monazite per cubic yard and were estimated to contain 4,400 short tons of monazite. About 600 short tons of monazite in sediments having an average tenor of 1.2 pounds of monazite per cubic yard was reported by Cuppels for the headwater parts of the main valley of Fairforest Creek at and northwest of Arcadia. The combined resource in monazite of alluvium in the main valleys of Beaverdam Creek and Reedy Creek was estimated to be 1,500 short tons at an average tenor of 0.7 pound of monazite per cubic yard. Several small creeks between Roebuck and Golightly at the southeast edge of the belt, and the main valley of Fairforest Creek between Beaverdam Creek and Buffalo Creek, were inferred to contain 1,400 short tons of monazite at an average tenor of 0.2 pound of monazite per cubic yard.

Parts of the valleys of the North Tyger River, Middle Tyger River, and South Tyger River in western Spartanburg County and extreme eastern Greenville County near the northwest edge of the monazite belt were estimated by Cuppels to contain at least 9,200 short tons of monazite in alluvium having an average tenor of 0.4 pound of monazite per cubic yard (Overstreet, Theobald, Whitlow, 1959, p. 710). As much as 11.9 pounds of monazite per cubic yard was found in one sample of gravel in the area, but 20 percent of the samples contained either no monazite or only a trace (N. P. Cuppels, written commun., 1954). The valley of North Tyger River upstream from Jordan Creek and the valley of Jordan Creek were estimated to have in combination 4,200 short tons of monazite in alluvium having an average tenor of 0.5 pound of monazite per cubic yard. In the valley of the Middle Tyger River upstream from the settlement of Duncan to the Beaverdam Creek area, including the lower valleys of Beaverdam Creek, Wolf Swamp Creek, and Spencer Creek, the tenor of the sediment was estimated to be only 0.1 pound of monazite per cubic yard, and the resources were inferred to be 1,700 short tons of monazite. The main valley of the South Tyger River from the vicinity of Duncan upstream to the county line has practically no flood plains. Small flood plains are present on Maple Creek south and southeast of Greer. The combined resources in monazite of the little flood plains on the South Tyger River above Duncan and on Maple Creek near Greer was estimated by Cuppels to be 3,300 short tons of monazite in sediment having an average tenor of 1.8 pounds of monazite per cubic yard. This high tenor results from the high average tenor of alluvium in Maple Creek, estimated to be 2.2 pounds of monazite per cubic yard. Maple Creek and the Greer area are in the core of the monazite belt, and concentrates commonly contain 20–30 percent of monazite.

The valleys of the North Tyger River and Middle Tyger River and their tributaries upstream from the junction of the rivers to the vicinity of Jackson Mills and Duncan were estimated by N. P. Cuppels (written commun., 1954) to contain at least 12,400 short tons of monazite. The distribution of monazite was found to be very variable, and tenors of alluvium in different streams ranged from 0.1 to 2.7 pounds of monazite per cubic yard with one stream, Grays Creek, being virtually barren of monazite. The drainage basins are in the narrowest part of the monazite belt in Spartanburg County. Downstream from the junction of the North Tyger River and South Tyger River, the main valley, also known as the North Tyger River, has broad and nearly continuous flood plains to the mouth of the South Tyger River. Large-volume low-tenor placers in this part of the river were estimated to contain about 5,400 short tons of monazite, and the combined resources were reported to be 17,800 short tons, the average tenor being 0.4 pound of monazite per cubic yard of sediment. Results of churn drilling in the large flood plain that extends downstream for 3.5 miles from the junction of the North Tyger River and Middle Tyger River, described below, show that the reconnaissance estimate of the amount of monazite is too low for the part of the river between this junction and the mouth of the South Tyger River.

The large flood plain at the junction of the North Tyger River and Middle Tyger River was explored by the U.S. Bureau of Mines in January 1953 with 16 churn-drill holes (Hansen and Cuppels, 1953, p. 4–5). The deposit is at the southeast edge of the monazite belt and has received its sediment from weathered rocks in and northwest of the belt. The flood plain to a distance of 3.5 miles downstream from the confluence was estimated to contain 33.7 million cubic yards of alluvium, mostly sand, silt, and clay. From 5.44 to 15.39 pounds of heavy minerals were estimated per cubic yard of sediment, the average being 9.35 pounds per cubic yard. Only 4.2 percent of the heavy minerals was estimated to be monazite. The average tenor was estimated to be 0.39 pound of monazite per cubic yard with a range from 0.16 to 1.08 pounds per cubic yard. Resources in monazite for this part of the flood plain were inferred to be 6,570 short tons. Estimations of other minerals included 51,200 short tons of ilmenite, 2,100 short tons of rutile, 13,400 short tons of zircon, 5,500 short tons of kyanite and sillimanite, 390 short tons of xenotime, and 23,600 short tons of garnet. (See table 79.)

TABLE 79.—*Mineralogical composition, in percent, of concentrates from composited samples of alluvium from two drill holes in the flood plain downstream from the confluence of the North Tyger River and Middle Tyger River in Spartanburg County, S.C.*

[Modified from Hansen and Cuppels (1955, table 2)]

	A	B	Arithmetic average
Ilmenite	36	29	32.5
Quartz	11	12	11.5
Garnet	13	17	15
Epidote	10	10	10
Amphibole and biotite	7	7	7
Zircon	10	7	8.5
Monazite	6.5	7.9	7.2
Kyanite and sillimanite	3	4	3.5
Magnetite	1	.5	.75
Rutile	1.4	1.3	1.35
Sphene	--------	1	.5
Xenotime	--------	.5	.25
Black opaque minerals	1.5	.2	.85
Total	100.4	97.4	98.90

Two samples of monazite from the deposit at the junction of the North Tyger River and Middle Tyger River were analyzed by the U.S. Bureau of Mines and were found to have the following percentages (Hansen and Cuppels, 1955, p. 18):

Sample	Percent	
	ThO_2	U_3O_8
A	5.87	0.79
B	5.66	.62
Average	5.76	.70

At the southeast boundary of the monazite belt, Ferguson Creek and other streams entering the South Tyger River in Spartanburg County were found by N. P. Cupples to contain at least 9,400 short tons of monazite in flood-plain sediments having an estimated average tenor of 0.4 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). Concentrates from streams in the core of the monazite belt near Reidville have as much as 40 percent of monazite, but concentrates from tributaries to the South Tyger River southeast of the core of the belt in the area downstream from Chickenfoot Creek contain only 1–5 percent of monazite (N. P. Cuppels, written commun., 1954). No large or rich deposits are present.

PARTS OF GREENVILLE COUNTY AND LAURENS COUNTY

Streams in the northern one-third of Greenville County are monazite free or, in the extreme northeastern part of the county, are the source of concentrates that have 1–5 percent of monazite. The area is at the northwest flank of the monazite belt. Monazite is present in most streams south of a nearly east-trending line between the head of the Enoree River and the point on the South Tyger River where it leaves Greenville County. Most of Greenville County south of that line is in the core of the monazite belt, and concentrates generally contain from 10 to 20 percent of monazite. In the southern part of the county between the Saluda River and Reedy River, concentrates commonly have 10–30 percent of monazite and locally as much as 60 percent. Along the southeast edge of Greenville County a broad monazite-bearing zone extends eastward 6–11 miles into Laurens County. Concentrates from alluvium in this area, which is part of the southeast flank of the monazite belt, contain from 1 to 10 percent of monazite.

Rutile is present in concentrates from several parts of the county, but in two areas all concentrates contain rutile. One is an area that extends eastward from a point just north of the city of Greenville. The area is about 4 miles across from north to south and reaches into Spartanburg County on the east. In the part between Greenville and Paris Mountain, concentrates contain from 1 to 10 percent of rutile and locally have as much as 20 percent. The other area overlaps the line between Greenville County and Laurens County and extends southward from the Enoree River to the Saluda River. Here concentrates contain from 1 to 5 percent of rutile.

Sillimanite makes up 1 percent of the minerals in concentrates from streams in most of central Greenville County in the core of the monazite belt, but it is absent along the border between Greenville County and Laurens County (Overstreet, 1962, fig. 1). It is most abundant in the rutile-rich area around Paris Mountain. The distribution of almandine in concentrates from alluvium conforms closely to that of sillimanite, rutile, and monazite. The central part of Greenville County is the richest in garnet, and at the core of the belt concentrates generally contain 5–20 percent of almandine. Along the border between Greenville County and Laurens County a zone where concentrates have 1–5 percent of almandine matches the southeast edge of the core of the monazite belt but does not extend as far eastward as the southeast edge of the flank of the belt.

Very large amounts of ilmenite are present in concentrates from streams in Greenville County south of the city of Greenville. In much of southern Greenville County concentrates contain from 70 to 90 percent of ilmenite. This ilmenite-rich zone persists into southwestern Laurens County, northwestern Abbeville County, and eastern, central, and western Anderson County.

Epidote and magnetite are common in monazite-bearing concentrates from the northwest and southeast flanks of the belt in Greenville County and

Laurens County (Overstreet and Griffitts, 1955, fig. 1). In the northeastern part of Greenville County and across the county north of Paris Mountain, epidote generally makes up 1–20 percent of the concentrate, and magnetite constitutes 20–70 percent. Along the south border of the county and in western Laurens County, epidote rarely makes up more than 1 percent of the concentrate, but magnetite is uniformly present in percentages that increase eastward from 5 percent along the county border to 50 percent along the southeast edge of the monazite belt.

During the period of active monazite mining in the Carolinas in the late 1800's and early 1900's, the principal center for the industry in Greenville County was between Mauldin and Simpsonville (p. 235) on tributaries to the Enoree River and Reedy River. Several localities north and west of Mauldin were also mined, but records of output have not been published.

The placers along monazite-bearing tributaries to the Enoree River in Greenville County and Laurens County were appraised by N. P. Cuppels in 1952, and placers along tributaries to the Reedy River were appraised by D. W. Caldwell in 1952 (Overstreet, Theobald, and Whitlow, 1959, p. 710). The main monazite-bearing streams entering the Enoree River are Mountain Creek, Gilder Creek, and Durbin Creek. Those tributary to the Reedy River are Laurel Creek, Huff Creek, Horse Creek, Rabon Creek, and Walnut Creek.

Mountain Creek and other streams in the upper reaches of the Enoree River northeast of the town of Greenville were estimated by Cuppels to contain at least 5,100 short tons of monazite in alluvium having an average tenor of 0.4 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). The area is on the northwest edge of the monazite belt. Gravel from riffles in the streams generally contains less than 5 pounds of monazite per cubic yard, and most of the alluvium has only about one-tenth of that tenor. None of the formerly worked monazite placers in Greenville County (p. 235) is in this area.

Gilder Creek and other tributaries to the Enoree River between the eastern outskirts of Greenville and a point on the Enoree River about a mile downstream from the northwest corner of Laurens County, including several small streams entering the Enoree from Spartanburg County, were estimated by N. P. Cuppels to contain at least 29,200 short tons of monazite in alluvium having an average tenor of 1.2 pounds of monazite per cubic yard (Overstreet, Whitlow, Theobald, 1959, p. 710). Several headwater branches of Gilder Creek were formerly mined for monazite (p. 235). The Wyatt Smith placer, the W. M. Burdin mine, and the F. A. Alston mine were cited by Sloan (1908, p. 135–136). Of these the F. A. Alston mine was said to be the best, but no record of its output was given, although monazite was shipped. Five Mile Creek at a locality about 6 miles east of Greenville was also cited by Sloan as a placer (p. 235). Seemingly this is one of the tributaries to Brushy Creek north of Gilder Creek, but it has not been otherwise identified.

In the Gilder Creek area the flood plains on the Enoree River are discontinuous and range in width from 150 to 600 feet except near the mouth of Gilder Creek where one widens to 1,600 feet. On the tributaries, flood plains are generally continuous and range in width from 200 to 400 feet. One flood plain on Gilder Creek is locally 1,000 feet wide. At most places the flood plain sediments in the valley of the Enoree River are 10–13 feet thick and on the tributaries are 6–11 feet thick (N. P. Cuppels, written commun., 1954). Inasmuch as the area is in the core of the monazite belt, all the flood-plain sediments contain monazite, and locally samples of riffle gravel from the head of Gilder Creek and Rocky Creek were reported by Cuppels to contain as much as 12–14 pounds of monazite per cubic yard. At several places on these creeks and Brushy Creek, gravel was estimated to have more than 20 pounds of ilmenite per cubic yard.

The largest placer recognized by Cuppels is along Peters Creek, Abner Creek, and the Enoree River between the mouths of these two streams. In this deposit alluvium having an average tenor of 1.2 pounds of monazite was estimated to contain 8,900 short tons of monazite (N. P. Cuppels, written commun., 1954). Estimates prepared by Cuppels of the average tenor and resources in monazite in the Gilder Creek area follow:

	Tenor (lb of monazite per cu yd)	*Resources (short tons)*
Brushy Creek	0. 7	1, 800
Rocky Creek	2. 0	4, 200
Dillard Creek	1. 9	1, 600
Abner Creek	1. 8	3, 300
Peters Creek	2. 1	3, 100
Gilder Creek	1. 5	10, 100
Enoree River and other streams	(1)	5, 100

[1] Not reported.

No part of the monazite belt southwest of Gilder Creek with the exception of Huff Creek is equal to the drainage basin of Gilder Creek as a potential source for monazite. Several streams in North Carolina southwest of the Catawba River are as good or better. These include Knob Creek, Hinton Creek, Floyds Creek, and the downstream part of Henry Fork.

Durbin Creek and other tributaries to the Enoree River in Greenville, Laurens, and Spartanburg Counties were estimated by N. P. Cuppels to have at least 7,200 short tons of monazite in alluvium having an average tenor of only 0.3 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). The area is on the east flank of the monazite belt. None of the streams is suitable for mining monazite.

Laurel Creek and adjoining streams in the upper reaches of the Reedy River in Greenville County were reported by D. W. Caldwell to contain at least 12,600 short tons of monazite in flood-plain sediments having an average tenor of 0.8 pound per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). The Reedy River rises on the southwest side of Paris Mountain. South-flowing tributaries to the river south of Paris Mountain have beheaded east-flowing streams that enter the Enoree River; thus, Laurel Creek has beheaded Gilder Creek and Richland Creek has captured the headwaters of Brushy Creek northeast of Greenville (D. W. Caldwell, written commun., 1954). Upstream from Greenville the flood plains on the Reedy River and its tributaries are broad, regular, and continuous, but downstream between Greenville and Conestee Lake they are irregular in width and discontinuous. Where they are broad and continuous the valleys are carved in massive granite and schist, and where they are irregular the valley walls are gneiss. Alluvium along the Reedy River between Paris Mountain and Conestee Lake averages 11.4 feet in thickness. On tributaries entering the river from the north the alluvium is a little deeper than on streams that enter from the south, but both sets of flood plains are shallower than those on the river.

Most of the area is northwest of the core of the monazite belt, but south of Greenville the streams are in the core of the belt. Concentrates from alluvium in the core contain 20–40 percent of monazite, but concentrates from streams on the northwest flank of the belt have only 1–5 percent of monazite. Monazite is associated with ilmenite and garnet in all the concentrates. Sillimanite, zircon, and magnetite are common in small amounts, and concentrates with sparse monazite have abundant epidote. Rutile is sparse. The distribution of heavy minerals in the stream sediments was shown by D. W. Caldwell (written commun., 1954) to be related to the kinds of rocks drained by the streams (table 80). Concentrates from drainage basins that expose epidote- and magnetite-bearing monazite-free massive granite in monazite-bearing schists contain appreciably less monazite and more epidote and magnetite than concentrates from basins that do not expose the massive granite. Structural relations have been interpreted to show that the monazite-free granite is posttectonic with respect to the episode of deformation in which monazite was formed in the schist and gneiss (Overstreet and Bell, 1962, map).

TABLE 80.—*Distribution of detrital heavy minerals in concentrates from riffle sand and gravel in relation to source rocks in the drainage basins of Laurel Creek and other tributaries to the Reedy River in Greenville County, S.C.*

[Modified from D. W. Caldwell (written commun., 1954). Symbol used: --, not calculated]

	Average of 7 samples from area underlain chiefly by granite gneiss		Average of 5 samples from area underlain chiefly by massive granite and schists	
	Abundance (percent)	Tenor (lb per cu yd)	Abundance (percent)	Tenor (lb per cu yd)
Monazite	18	6.1	3	0.5
Ilmenite	60	22.8	56	3.8
Garnet	17	5.4	2	.2
Zircon	1	.3	4	.3
Rutile	Trace	--	1	.1
Sillimanite	1	.3	10	.6
Magnetite	3	--	10	--
Epidote	Trace	--	14	--

The broad valleys and large flood plains upstream from Greenville are in the area where the monazite-free granite is present; hence, these fine deposits of fluvial sediments contain only about 0.2 pound of monazite per cubic yard. Downstream from Greenville where irregular and interrupted flood plains are found, the monazite-free granite is absent, and the alluvium in different streams was reported to contain from 1.2 to 1.8 pounds of monazite per cubic yard (D. W. Caldwell, written commun., 1954):

	Tenor (lb of monazite per cu yd)	*Resources (short tons)*
Headwaters of Reedy River	0.2	1,400
Long Branch	.2	(1)
Reedy River downstream from Greenville to Conestee Lake	1.5	2,800
Richland Creek	1.8	2,400
Brushy Creek	1.4	2,600
Laurel Creek	1.3	2,900
Other streams	(2)	500
Total	--------	12,600

[1] Less than 100 tons.
[2] Not reported.

The Alexander brothers' placer mentioned by Sloan (1908, p. 133) was probably on a branch of Brushy Creek, and the J. S. Hill, Jr., placer was on a downstream tributary to Laurel Creek east of Conestee Lake (Sloan, 1908, p. 134).

Huff Creek and neighboring tributaries to the Reedy River between Conestee Lake and Fork Shoals in Greenville County were estimated by D. W. Caldwell to contain 17,900 short tons of monazite in alluvium having an average tenor of 2.1 pounds of monazite per cubic yard (Overstreet, Theobald, and

Whitlow, 1959, p. 710). Except for the Gilder Creek area this is probably the site of the richest monazite deposits in the South Carolina Piedmont south of Cherokee County. Sloan (1908, p. 134–135) listed five placer deposits on northern tributaries to the Reedy River immediately downstream from Conestee Lake. These were the Thomas Fowler placer, the A. White placer, the Molly Garrett placer, the Brooks mine, and the J. R. Bramlet placer (p. 235). A large output was attributed to the Brooks mine, but records have not been published.

The Huff Creek area is underlain by granite gneiss, biotite schist, sillimanite schist, and biotite gneiss in the core of the monazite belt (D. W. Caldwell, written commun., 1954; Overstreet, 1962, fig. 2). The widest flood plains are in valleys carved in the schists. Valleys in gneiss are narrow, and the flood plains are small and discontinuous. Mostly the flood plains are 200–750 feet wide in the areas of schist and 200–300 feet wide in the areas underlain by gneiss. At its widest the flood plain on Huff Creek reaches 1,300 feet in width and that on the Reedy River attains 1,700 feet, but flood plains on the smaller streams do not exceed 600 feet. Sediments on the tributaries to the Reedy River are about 6–12 feet thick, and alluvium in the valley of the river is about 14–22 feet thick.

Concentrates from stream sediments contain as much as 60 percent of monazite at the center of the area just west of the junction of Rock Creek with the Reedy River (D. W. Caldwell, written commun., 1954). Outward from the center the amount of monazite decreases to a lower limit of about 30 percent of the concentrate. Typical suites of heavy minerals consist of ilmenite, monazite, and garnet with small amounts of magnetite, zircon, and sillimanite. Locally a trace of rutile, staurolite, tourmaline, amphibole, epidote, sphene, and xenotime is present. In more than one-third of the samples of riffle gravel and one-fifth of the samples of riffle sand, the tenor in monazite was estimated to exceed 5 pounds per cubic yard. The average tenor of alluvium from grass roots to bedrock is also high (D. W. Caldwell, written commun., 1954):

	Tenor (lb of monazite per cu yd)	*Resources (short tons)*
Rock Creek	1.2	1,800
Upper part of Huff Creek	4.3	2,500
North central Huff Creek and tributary	4.5	3,800
South central Huff Creek	2.8	3,300
Lower part of Huff Creek	1.4	900
Baker Creek	2.2	1,400
Head of Little Creek	3.6	1,700
Other streams	(1)	2,500
Total	--------	17,900

Not reported.

Streams having the highest tenors in monazite, ilmenite, garnet, zircon, and sillimanite are in areas chiefly underlain by granite gneiss. Streams on biotite schist and biotite gneiss are the poorest sources for monazite. The upper part of Huff Creek and the head of Little Creek seem to contain the highest-grade deposits in the area, but neither of these localities seems to have been mined.

Horse Creek rises in Greenville County and enters the Reedy River in Laurens County. The creek and nearby tributaries to the Reedy River are southeast of the core of the monazite belt, and the southwestern and southeastern parts of the area are even outside the southeast flank of the belt. Most concentrates are lean in monazite and some are barren. The tributaries to the Reedy River were estimated to contain about 3,000 short tons of monazite in alluvium having an average tenor of 0.3 pound per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). Alluvium along the large flood plain in the valley of the Reedy River between Fork Shoals in Greenville County and the mouth of Horse Creek in Laurens County was thought possibly to contain as much as 0.5 pound of monazite per cubic yard because the river rises a few miles north of the monazite belt and traverses it (D. W. Caldwell, written commun., 1954); the alluvium probably has only about half that tenor.

The headwaters of North Rabon Creek and South Rabon Creek originate near Fountain Inn in Greenville County and flow southward to join about 7 miles west of the city of Laurens in Laurens County. From this junction the stream is known as Rabon Creek. Rabon Creek empties into Lake Greenwood. North Rabon Creek and South Rabon Creek rise on the east side of the core of the monazite belt, and the mouth of Rabon Creek is on the southeast flank of the belt. Resources in monazite of the two streams to their confluence was estimated by D. W. Caldwell to be about 12,600 short tons in alluvium having an average tenor of 0.4 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). The resources in North Rabon Creek were estimated to be 5,000 short tons in sediments averaging 0.3 pound of monazite per cubic yard, and in South Rabon Creek they were said to be 7,600 short tons in alluvium having an average of 0.5 pound of monazite per cubic yard (D. W. Caldwell, written commun., 1954). An estimate of 10,900 short tons of monazite was made for the same area from the results of drilling 19 holes in January and February 1953 (Hansen and Caldwell, 1955, p. 6). The average tenor of the flood-plain sediments as found by churn drilling is 0.42 pound of monazite per cubic yard.

Sediments in the flood plains of North Rabon Creek and South Rabon Creek contain an estimated 5.5 pounds of black sand per cubic yard. This sand consists mostly of ilmenite and amphibole.

Mineralogical composition, in percent, of concentrates from sediment from drill holes in the flood plain of South Rabon Creek, Laurens County, S.C.

[Modified from Hansen and Caldwell (1955, table 3)]

	Upstream	*Downstream*
Ilmenite	43	31
Amphibole and biotite	19	7
Quartz	14	13
Monazite	7. 4	9. 4
Xenotime	. 5	. 3
Zircon	3. 5	5. 6
Garnet	3	2
Epidote	2	24
Magnetite	3	. 1
Rutile	2	5
Kyanite and sillimanite	1	1
Opaque minerals	1	1
Total	99. 4	99. 4

Monazite from North Rabon Creek and South Rabon Creek was analyzed by the U.S. Bureau of Mines and found to contain the following percentages of thorium oxide (Hansen and Caldwell, 1955, p. 16):

	Percent	
	ThO_2	U_3O_8
North Rabon Creek	7. 85	0. 33
	6. 95	. 30
	6. 12	. 46
South Rabon Creek	5. 51	. 49
	6. 30	. 49
Average	6. 55	. 41

Most of the monazite in the Rabon Creek area comes from biotite granite gneiss (D. W. Caldwell, written commun., 1954). The amount of thorium oxide in this monazite is somewhat greater than the amount in monazite from placers on the Broad River, Tyger River, and Big Generostee Creek, where the monazite comes mainly from schists and gneiss.

Monazite was reported by Sloan (1908, p. 129) to occur on Walnut Creek, which is the southernmost of the large western tributaries to the Reedy River. The creek and several small western and northern tributaries to the river in northwestern Laurens County about 5 miles upstream from Lake Greenwood are on the southeast flank of the monazite belt. Concentrates from these streams consist of dominant ilmenite and magnetite having 1–20 percent of monazite and a trace of rutile and epidote (D. W. Caldwell, written commun., 1954). Sporadically distributed associated heavy minerals are, in order of frequency of appearance: amphibole, zircon, garnet, staurolite, sphene, sillimanite, kyanite, xenotime, tourmaline, and spinel. The streams were appraised by Caldwell in 1952 and were estimated to contain about 1,700 short tons of monazite (Overstreet, Theobald, and Whitlow, 1959, p. 710). The average tenor of alluvium was estimated to be 0.5 pound of monazite per cubic yard.

PARTS OF GREENVILLE, PICKENS, ANDERSON, ABBEVILLE, GREENWOOD, OCONEE, AND LAURENS COUNTIES

The northwest edge of the core of the monazite belt enters in northwest Anderson County where its boundary with Pickens County reaches the Saluda River (Overstreet, 1962, fig. 2). From this point the northwest edge of the core of the belt passes southward into Abbeville County at the place where the Rocky River crosses the boundary between Anderson County and Abbeville County. The core of the belt is in eastern Anderson County. Concentrates from the core in this area contain only 5–10 percent of monazite, and this area is the leanest part of the core in South Carolina. Locally, as at the Saluda River near Pickens County and near Abbeville County and at the Rocky River at the Abbeville County line, monazite makes up as much as 20 percent of the concentrate. To the northwest of the core, there is a broad area in southwestern Anderson County that constitutes the northwest flank of the belt where concentrates contain between 1 and 5 percent of monazite. The northwest edge of the flank of the belt extends west-southwestward 1–4 miles south of the north border of Anderson County and crosses the Tugaloo River about a mile upstream from the mouth of the Seneca River. A few small outlying areas where concentrates from alluvium contain less than 5 percent of monazite occur along the south borders of Pickens County and Oconee County. The most notable of these is about 5 miles north of the point where the boundary between Oconee County and Anderson County touches the Tugaloo River.

The southeast edge of the core of the monazite belt passes west-southwestward from the intersection of the Saluda River with the Anderson-Abbeville County line. The core is only 4–8 miles wide. It occupies most of the area between the Rocky River and Little River in Abbeville County. The broad southeast flank of the monazite belt enters Abbeville County and Greenwood County from Laurens County. Its full width in Greenwood County has not been determined, but it extends southeastward at least to the upper reaches of Lake Greenwood.

Rutile in abundances up to 20 percent of the concentrate, but mainly less than 5 percent, is present more or less along the core of the monazite belt southwestward across northern Abbeville County from the

Saluda River to the Rocky River. It is also present in northern Greenwood County near the Saluda River and in southern Anderson County near the Rocky River. Elsewhere in Anderson County, concentrates have less than 1 percent of rutile except for a 40-square-mile area between the city of Anderson and the Seneca River and four scattered small areas from which one to three rutile-bearing concentrates were collected. Rutile is also present in the monazite-rich outlying area in Oconee County 5 miles north of the Tugaloo River.

Sillimanite is absent in concentrates from most of Anderson County, and it is not present in concentrates from Pickens County or Greenwood County. Its principal occurrence in this part of the monazite belt is along the Saluda River from a point about a mile downstream from the Pickens County line to a point about 8 miles upstream from the line between Anderson County and Abbeville County. Sillimanite is also present in concentrates from the core of the belt at the head of the Little River and adjacent parts of the Rocky River in Anderson County and Abbeville County. Silimanite is present in concentrates from the monazite-rich outlying area in Oconee County 5 miles north of the Tugaloo River.

Almandine is absent from or sparse in most concentrates from alluvium in northern, western, and southwestern Anderson County. It is most common in the core of the belt along the Saluda River northeast of the city of Anderson. It is also present in low concentrations on the southeast flank of the belt in northern Greenwood County and Abbeville County and in the core of the belt from the headwaters of the Little River to the Rocky River at the border between Anderson County and Abbeville County. Almandine makes up 1–5 percent of the heavy minerals in concentrates from the monazite-rich outlying area in Oconee County 5 miles north of the Tugaloo River.

Ilmenite is the most abundant component of concentrates from alluvium in eastern, central, and western Anderson County, and it is also very abundant in concentrates from the monazite-bearing area in Oconee County north of the Tugaloo River. In these areas ilmenite makes up 70–90 percent of the concentrate. Elsewhere in Anderson County and in adjacent parts of Pickens, Oconee, and Abbeville Counties, ilmenite composes 10–60 percent of the concentrate. Narrow zones having 70 percent or more of ilmenite in concentrates from alluvium are present in northeastern Abbevile County and Greenwood County.

Epidote is commonly present in amounts ranging from 1 to 5 percent of the concentrate along the northwest flank of the belt, in areas barren of monazite in northeastern and central Anderson County, and in southern Pickens County and Oconee County. Epidote is also common in concentrates from the core and southeast flank of the belt in northern Abbeville County and Greenwood County. It is generally absent from the small monazite-rich outlying area in Oconee County north of the Tugaloo River.

Magnetite is scarce in concentrates from the core of the monazite belt in Anderson County and Abbeville County, but it is common in concentrates from the flanks of the belt or in monazite-free parts of Pickens, Oconee, Anderson, Abbeville, and Greenwood Counties (Overstreet and Griffitts, 1955, pl. 1).

Ten areas of monazite-bearing streams in these counties were appraised by D. W. Caldwell in 1952 (Overstreet, Cuppels, and White, 1955; Overstreet, Theobald, and Whitlow, 1959, p. 710). Four of these areas are drained by tributaries to the Saluda River in Greenville, Pickens, Anderson, Abbeville, and Greenwood Counties. Six are drained by tributaries to the Savannah River and are discussed in a following section under "Parts of Anderson, Abbeville, and Oconee Counties." The four areas in parts of Greenville, Pickens, Anderson, Abbeville, and Greenwood Counties are around Big Brushy Creek, Grove Creek, Broad Mouth Creek, and Turkey Creek.

Big Brushy Creek rises northwest of the monazite belt in Pickens County, flows 12 miles southeastward through Pickens County and Anderson County, and empties into the Saluda River near the town of Piedmont (D. W. Caldwell, written commun., 1954). Upstream along the Saluda River from the mouth of Big Brushy Creek to Saluda Lake several small monazite-bearing tributaries enter the river from Anderson County and Pickens County and eight very short streams reach the river from Greenville County. All these streams are northwest of the core of the monazite belt which results in alluvium having the low average tenor of only 0.2 pound of monazite per cubic yard. Resources were estimated to be about 1,900 short tons of monazite (Overstreet, Theobald, and Whitlow, 1959, p. 710).

Grove Creek enters the Saluda River in Greenville County about 3.5 miles downstream from Pelzer which is on the other side of the river in Anderson County (D. W. Caldwell, written commun., 1954). The lower tributaries to Grove Creek were mined at several places in the early 1900's (Sloan, 1908, p. 133); the Berry Waldrop placer and the Dave Terry placer were mentioned (p. 235). Monazite from the Waldrop deposit was said by Sloan to be an important factor in the South Carolina industry. On the opposite side of the Saluda River, placers were also known in Anderson County on lower tributaries to Hurricane

Creek 3.5 miles north-northwest of Pelzer and on tributaries to the middle part of Big Creek about 1 mile south of Pelzer (p. 235). The output, if any, at these deposits was not recorded (Sloan, 1908, p. 132).

The headwaters of Grove Creek, Hurrican Creek, Big Creek, and other streams in this area originate in granite gneiss and interlayered biotite schist northwest of the core of the monazite belt. Their lower ends, or middle and lower reaches are in the core, and eastern tributaries to Grove Creek rise in the core of the belt. Sillimanitic rocks are especially common in and near the parts of Hurricane Creek and Big Creek where placers were formerly mined. Ilmenite is the most abundant mineral in concentrates from sediments in the Grove Creek area (D. W. Caldwell, written commun., 1954):

	Average tenor of riffle sediments (lb per cu yd)		
	Grove Creek	Hurricane Creek	Big Creek
Ilmenite	17.5	12.7	9.1
Monazite	1.4	1.3	2.2
Zircon	.5	.9	.2
Garnet	.5	1.8	.8
Sillimanite	.1	.3	.4

Areas rich in magnetite and epidote at the head of Hurricane Creek are virtually devoid of monazite.

Resources in monazite in flood-plain sediments along Grove Creek and adjacent tributaries to the Saluda River were estimated by Caldwell to be about 5,600 short tons in alluvium having an average tenor of 0.3 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). The tenors and resources of individual streams were reported (D. W. Caldwell, written commun., 1954) to be as follows:

	Tenor (lb of monazite per cu yd)	*Resources (short tons)*
Hurricane Creek	0.5	1,500
Grove Creek	.2	1,900
Big Creek	.4	2,200
Total	--------	5,600

Broad Mouth Creek and other tributaries to the Saluda River in Anderson, Greenville, Abbeville, and Laurens Counties were estimated by D. W. Caldwell to have at least 14,300 short tons of monazite in flood-plain deposits having an average tenor of 0.8 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). Broad Mouth Creek heads in east-central Anderson County and enters the Saluda River in Abbeville County. In the same general area, Little Creek and Tony Creek flow into the Saluda River from Abbeville County and Anderson County, respectively, and Mountain Creek reaches the river in Greenville County.

Biotite gneiss and biotite schist are the principal rocks in the drainage basins of Broad Mouth Creek and Mountain Creek (D. W. Caldwell, written commun., 1954). Locally granite gneiss and weakly foliated granite crop out. Throughout the area, but especially around Honea Path in Anderson County, dikes and sills of pegmatite are common. Concentrates from alluvium in the western and central parts of the area are much leaner in monazite than concentrates from the southern and eastern parts. Around Honea Path and between that town and the point where the Anderson-Abbeville County line meets the Saluda River, concentrates contain as much as 30 percent of monazite. Concentrates consist mostly of ilmenite but have some monazite, magnetite, zircon and small amounts of garnet and rutile; epidote and amphibole are present locally. Riffle sand was reported to contain as much as 13.8 pounds of ilmenite per cubic yard (D. W. Caldwell, written commun., 1954):

	Average tenor of riffle sediments (lb per cu yd)		
	Mountain Creek	Little Creek	Broad Mouth Creek
Ilmenite	9.5	8.6	13.8
Monazite	1.0	1.0	1.8
Zircon	Trace	.1	.5
Garnet	.1	Trace	.1
Rutile	.1	Absent	Trace

Several samples of riffle gravel from small streams around Honea Path in Anderson County were found by Caldwell to have a tenor of 5 pounds of monazite per cubic yard or more. Detrital monazite had been mined near the town in the early 1900's (Sloan, 1908, p. 129).

The tenor and resources in monazite of sediments along individual streams in the Broad Mouth Creek area were estimated by D. W. Caldwell (written commun., 1954) to be as follows:

	Tenor (lb of monazite per cu yd)	*Resources (short tons)*
Mountain Creek	0.7	2,800
Tony Creek	.4	400
Little Creek	.7	1,000
Broad Mouth Creek	1.0	9,000
Other streams	(1)	1,100
Total		14,300

1 Not reported.

Sediments along the large flood plains on the Saluda River in this area probably contain about a quarter of a pound of monazite per cubic yard.

The headwaters of Turkey Creek originate in eastern Anderson County at Honea Path, and the stream enters Lake Greenwood on the Saluda River in Greenwood County. The stream rises in the core of the monazite belt and flows out the southeast flank of the belt. Alluvium in the headwaters of Turkey Creek contains about 1.2 pounds of monazite per cubic yard, but sediments in the lower reaches of the stream have only about 0.2 pound of monazite per cubic yard (D. W. Caldwell, written commun., 1954). Resources in monazite were estimated by Caldwell to be about 4,500 short tons, and the average tenor of alluvium in Turkey Creek and nearby tributaries to the Saluda River was estimated to be 0.4 pound of monazite per cubic yard from grass roots to bedrock (Overstreet, Theobald, and Whitlow, 1959, p. 710).

PARTS OF ANDERSON, ABBEVILLE, AND OCONEE COUNTIES

Placers in six areas drained by monazite-bearing tributaries to the Savannah River in parts of Anderson, Abbeville, and Oconee Counties were appraised by D. W. Caldwell in 1952, and one of the areas was explored by the U.S. Bureau of Mines in 1953. The areas examined by Caldwell are around Big Beaverdam Creek in central Anderson County, Broadway Creek, Hogskin Creek, Big Generostee Creek, Saddler Creek, and Big Beaverdam Creek and Little Beaverdam Creek in western Anderson County and Oconee County.

Big Beaverdam Creek in central Anderson County is the headwaters of the Rocky River. It is north and east of the city of Anderson in an area underlain by granite gneiss, granite, biotite schist, and biotite gneiss (D. W. Caldwell, written commun., 1954). It is on and northwest of the northwest flank of the monazite belt in an area lean in or devoid of monazite. Flood-plain sediments were estimated to have an average tenor of only 0.1 pound of monazite per cubic yard, and the resources were appraised as about 2,700 short tons of monazite (Overstreet, Theobald, and Whitlow, 1959, p. 710).

The northeastern and southern parts of the area drained by Broadway Creek and other streams tributary to the Rocky River in Anderson County are underlain by monazite-bearing crystalline rocks, but the rocks in the western, central, and eastern parts of the area are very lean in or lack monazite. Therefore, alluvium in the northeastern and southern parts of the area contains more detrital monazite than alluvium in the other parts of the area (D. W. Caldwell, written commun., 1954).

The average tenor and total resources in monazite were estimated to be 0.5 pound per cubic yard and about 15,000 short tons (Overstreet, Theobald, and Whitlow, 1959, p. 710):

	Tenor (lb of monazite per cu yd)	Resources (short tons)
Northeastern:		
West Rock Creek	1.9	2,300
Watermellon Creek	.4	600
East Rock Creek	.2	100
Broadway Creek to mouth of Cupboard Creek	.5	1,300
Cupboard Creek	.7	1,550
Central and eastern:		
Broadway Creek to Broadway Lake	.2	220
Pea Creek	.2	165
Neal Creek	Trace	Trace
Beaver Creek	.3	1,550
Cherokee Creek	.0	None
Upstream part of Hen Coop Creek	Trace	Trace
Southern:		
Downstream part of Hen Coop Creek	1.1	5,000
Bear Creek	.8	2,100
Western:		
Governors Creek	.3	185
Average, weighted	.5	15,070

Concentrates from alluvium in the monazite-bearing parts of the area had less zircon, magnetite, and ilmenite, and more garnet and sillimanite than concentrates from alluvium in the monazite-free parts of the area (D. W. Caldwell, written commun., 1954).

Hogskin Creek and a group of other streams in southeastern Anderson County and northeastern Abbeville County are the headwaters of the Little River in the core of the monazite belt. Biotite schist, biotite gneiss, and granite gneiss are the main varieties of rocks underlying the drainage basins. Ilmenite is the principal mineral in the concentrate. It is accompanied by much smaller amounts of monazite, magnetite, garnet, zircon, rutile, and sillimanite. Changes take place between the northern and southern parts of the area in the composition of concentrates from gravel and coarse sand in the streams. The variations in the same class of sediment are related to changes in the dominant types of rocks in the drainage basins. In northern streams, such as Barker Creek and Blue Barker Creek, where biotite schist and biotite gneiss are common, ilmenite is more abundant than in southern streams, such as Hogskin Creek and Little Hogskin Creek, where granite gneiss or interlayered schists and granite gneiss are dominant. Another southward change in the composition of concentrates from gravel and coarse sand is an increase in monazite, zircon, and rutile. The amounts of garnet and sillimanite remain

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about the same (D. W. Caldwell, written commun., 1954):

	Tenor (lb of monazite per cu yd)	
	Northern streams	Southern streams
Ilmenite	4 –50	0.9 –35.7
Monazite	.1 – 6	.4 – 8.3
Zircon	0 – 1.2	.06– 2.1
Rutile	0	0 – 1.0
Garnet	.07– .6	0 – 1.0
Sillimanite	0 – .6	0 – .3

These variations are only faintly reflected in the average tenor for monazite in all classes of sediment. As estimated by Caldwell the average tenor of Barker Creek and its tributaries is 1.1 pounds of monazite per cubic yard, and that of Hogskin Creek and its tributaries is 1.4 pounds per cubic yard. Resources in these two basins were estimated to be 5,000 short tons and 7,000 short tons, respectively. Other streams in the area bring the resources to about 15,300 short tons of monazite in sediments having an average tenor of 1.2 pounds of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710).

Big Generostee Creek rises west of the city of Anderson and flows southwestward for 14 miles to the Savannah River in Anderson County. The largest tributary to Big Generostee Creek is Mountain Creek, which rises south of Anderson and enters Big Generostee about 6 miles upstream from the Savannah River. Biotite schist and biotite gneiss are the main varieties of rock in the basins of Mountain Creek and Big Generostee Creek upstream from its junction with Mountain Creek. From the junction to the Savannah River the basin of Big Generostee is underlain chiefly by granite gneiss. Flood plains are long, broad, and continuous from the headwaters to within about 2 miles of the Savannah River. For the most part the depth of the flood-plain sediments is about 7.5–14 feet, but locally the depth can be as much as 24 feet. Valley floors beneath the alluvium are flat and consist of saprolite.

The streams are on the northwest flank of the monazite belt where concentrates from alluvium contain a trace to 5 percent of monazite. The upper parts of Mountain Creek are very lean in monazite. Very large percentages of ilmenite are present throughout the area, which tends to reduce compositional differences among the sediments from different streams. Zircon occurs in about two-thirds of the concentrates and is locally very abundant in Mountain Creek. Rutile, garnet, and sillimanite are sparsely present, small amounts of epidote are common, and amphibole is sporadically distributed in small percentages (D. W. Caldwell, written commun., 1954).

Resources in monazite were appraised by Caldwell in 1952 as about 11,000 short tons in sediment having an average tenor of 0.5 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). The valleys of Big Generostee Creek and Mountain Creek were explored with 12 churn-drill holes by the U.S. Bureau of Mines in 1953 and were estimated to contain 9,500 short tons of monazite (Hansen and Caldwell, 1955, p. 22). Alluvium in these streams was estimated by the Bureau to contain 12 pounds of black sand per cubic yard including 0.44 pound of monazite. Monazite from Big Generostee Creek was analyzed by the U.S. Bureau of Mines and found to contain 4.21 percent of ThO_2 and 0.44 percent of U_3O_8 (Hansen and Caldwell, 1955, p. 24).

Individual streams in the area, and segments of Big Generostee Creek display generally decreasing average tenors in monazite southward from the head of the basin (D. W. Caldwell, written commun., 1954):

	Tenor (lb of monazite per cu yd)	Resources (short tons)
Whitner Creek and Crawford Creek	1.6	2,850
Three Mile Creek, Five Mile Creek, Richland Creek, and Big Generostee Creek to a point a mile downstream from Richland Creek	1.1	4,100
Big Generostee Creek to the mouth of Mountain Creek	.2	330
Big Generostee Creek to the Savannah River	Trace	-------
Mountain Creek	.1	650
Devil Fork Creek	.6	1,250
Weem Creek	.2	460
Other streams	(1)	1,730
Total	---------	11,370

[1] Not reported.

Saddler Creek and three short, steep tributaries to the Savannah River and Seneca River about 15 miles west of Anderson in Anderson County are on the northwest flank of the monazite belt in an area underlain in the south by granite gneiss and in the north by biotite schist and biotite gneiss. Alluvium in the streams on the granite gneiss is about twice as rich in monazite as alluvium along the streams in the schist. Resources of these streams were estimated in 1952 by D. W. Caldwell to be about 3,900 short tons of monazite in sediment having an average tenor of 2.0 pounds of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710).

Big Beaverdam Creek and Little Beaverdam Creek in western Anderson County and southwestern Oconee County partly drain an area of monazite-rich crystalline rocks west of the monazite belt and partly drain monazite-free rocks. The creeks head in Oconee County and flow southeastward to the Tugaloo River.

Along their lowermost parts the streams have cut gorges in unweathered biotite schist and biotite gneiss. Upstream from the gorges the streams have continuous flood plains of irregular width which extend to the very heads of the creeks. On both streams the widest flood plains begin at the upper ends of the gorges and extend 1.5 miles upstream on Big Beaverdam Creek and 1.2 miles upstream along Little Beaverdam Creek. At their widest parts these two flood plains are 2,400 feet and 1,700 feet across, respectively.

Concentrates from monazite-bearing parts of the drainage basins of the two streams contain more garnet, ilmenite, rutile, and sillimanite than concentrates from the monazite-free parts of the basins (D. W. Caldwell, written commun., 1954). Monazite-free concentrates have more zircon, magnetite, and epidote than concentrates containing monazite. Sediments along Little Beaverdam Creek and Cleveland Creek have less monazite, garnet, and ilmenite, and more epidote and magnetite than sediments on Big Beaverdam Creek upstream from the mouth of Cleveland Creek.

Remnant deposits of gravelly silt lie on an irregular erosion surface about 20 feet higher than the present valley floor on the west side of Big Beaverdam Creek at two points situated about 1.3 miles northwest of the Oconee County line and 2 miles southeast of the county line. A similar deposit occurs on the east side of Little Beaverdam Creek 1.5 miles northwest of the Oconee County line. Heavy-mineral suites from the terrace deposits have less of the unstable minerals and more of the stable minerals than do suites from the present flood plain sediments (table 81). Monazite is one of the minerals whose relative abundance is increased by the interstratal solution of the unstable heavy minerals.

TABLE 81.—*Relative abundance of stable and unstable heavy minerals in terrace gravel and riffle sediments in Big Beaverdam Creek and Little Beaverdam Creek in Oconee and Anderson Counties, S.C.*

[Modified from D. W. Caldwell (written commun., 1954). Symbols used: M, terrace gravel has more than present riffle sediment; L, terrace gravel has less than present riffle sediment; Ab, absent in all samples compared; U, unique to sample of terrace gravel; ID, insufficient data]

	Big Beaverdam Creek—		Little Beaverdam Creek
	Upstream from county line	Downstream from county line	
Monazite	M	M	M
Ilmenite	M	M	M
Rutile	U	U	M
Zircon	L	M	M
Sillimanite	Ab	U	Ab
Garnet	L	L	L
Magnetite	L	L	L
Amphibole	Ab	U	Ab
Epidote	L	ID	L

The resources of monazite along Big Beaverdam Creek and Little Beaverdam Creek were estimated by D. W. Caldwell to be about 13,000 short tons in flood-plain sediments having an average tenor of 0.5 pound of monazite per cubic yard (Overstreet, Theobald, and Whitlow, 1959, p. 710). Continous flood plains extending upstream along Big Beaverdam Creek from the head of the gorge above the Tugaloo River to the head of the creek, exclusive of sediment in Cleveland Creek, are the richest parts of the area. Alluvium in this valley was estimated by D. W. Caldwell (written commun., 1954) to contain about 7,500 short tons of monazite and to have an average tenor of 0.9 pound of monazite per cubic yard.

UNCONSOLIDATED SEDIMENTARY ROCKS IN THE COASTAL PLAIN PROVINCE

The distribution of monazite in unconsolidated sedimentary rocks in the Atlantic Coastal Plain physiographic province of South Carolina is generally poorly known. Practically all published data on the occurrence of monazite in rocks of Cretaceous and Tertiary age are indirect. Measurements of radioactivity of concentrates from grab samples of Cretaceous and Tertiary sedimentary rocks were made by Lincoln Dryden, and the observed radioactivity was interpreted in terms of monazite in the raw sediment (Dryden, 1958, p. 401–405). Anomalies in natural gamma aeroradioactivity over parts of Saluda, Lexington, Calhoun, Orangeburg, Dorchester, Colleton, Hampton, Allendale, Bamberg, Barnwell, Aiken, and Edgefield Counties were interpreted by Guillou and Schmidt (1960) and by Schmidt (1961; 1962, p. 29–38) as resulting from monazite in residual soil derived from Upper Cretaceous and Eocene strata. These studies indicate that a gradual diminution takes place seaward in the amount of monazite in the Coastal Plain formations. The studies also suggest that monazite in the younger formations was derived from reworked parts of older sedimentary rocks. No place is known in South Carolina where the amount of monazite in the Cretaceous and Tertiary sediments is sufficiently great to form a workable fossil placer. These sedimentary rocks have served as proximate sources from which monazite has been reconcentrated to form Pleistocene and Recent fluvial and littoral placers (Mertie, 1953, p. 12–13; Siple and others, 1959).

Highly detailed information on the amount of monazite in unconsolidated sediments of Quaternary age has been published for small areas in the South Carolina Coastal Plain that were explored for detrital monazite and for one area that was mined. Similar information covering more extensive areas of exploration is privately held.

DEPOSITS OF CRETACEOUS AGE

The oldest unconsolidated sediments in the Atlantic Coastal Plain in South Carolina are strata of the Tuscaloosa Formation, Black Creek Formation, and Peedee Formation of Late Cretaceous age. The Tuscaloosa rests on crystalline rocks, generally crops out along the inner edge of the Coastal Plain, and dips gently toward the southeast. Toward the southeast the Cretaceous formations are overlain by progressively younger sedimentary rocks of Tertiary age. Locally in South Carolina the Tertiary formations are widely transgressive, overlapping older formations and lying directly on crystalline rocks. Thus, in some areas the inner edge of the Coastal Plain is marked by Tertiary sedimentary rocks instead of by beds of Cretaceous age.

The Tuscaloosa Formation consists dominantly of silty and clayey sand, commonly pebbly, and associated pebble beds and lenticular masses of clay. The formation is highly variable, and crossbedding, lensing, and channel fillings are exposed in almost every outcrop (Lang and others, 1940, p. 32–43; Dryden, 1958, p. 397). The Black Creek and Peedee Formations are well bedded and more uniform than the Tuscaloosa. The Black Creek consists of very dark gray laminated clay and micaceous sand (Cooke, 1936, p. 25). It rests unconformably on the Tuscaloosa and in South Carolina is unconformably overlain by the Peedee Formation or younger sedimentary rocks. In South Carolina the Peedee is the youngest of the Cretaceous formations. It is gray sandy marl interbedded with thin layers of hard marlstone (Cooke, 1936, p. 32–33).

Typically concentrates from the Cretaceous sedimentary rocks consist of about 50 percent ilmenite and leucoxene and, in approximate order of abundance, variable quantities of zircon, rutile, monazite, staurolite, kyanite, sillimanite, tourmaline, and spinel (Dryden, 1958, p. 393). Epidote, garnet, and hornblende are absent despite their common presence in the pre-Cretaceous crystalline rocks.

Concentrates prepared by Lincoln Dryden from 151 grab samples from the Tuscaloosa Formation, two samples from the Black Creek Formation, and one sample from the Peedee Formation were examined for radioactivity in the same way that samples from Alabama, Georgia, and North Carolina were processed (Dryden, 1958, p. 411–415). The weight percentage of monazite in the concentrate was interpreted from the radioactivity of the concentrate, and for most concentrates the weight percentage was recalculated to inferred pounds of monazite per cubic yard of sedimentary rock. By these procedures, 143 of the 151 samples of Tuscaloosa were inferred to be monazite bearing, both samples from the Black Creek Formation were assumed to contain monazite, and the sample from the Peedee Formation was interpreted to be barren of monazite.

The two samples from the Black Creek Formation were inferred to contain 0.01 and 0.1 pound of monazite (Dryden, 1958, p. 405). They came from Dillon County at localities respectively southwest and south of the town of Dillon.

The amount of monazite in the 143 monazite-bearing samples of the Tuscaloosa Formation was estimated by Dryden (1958, p. 401–405) to range from 0.01 to 1.68 pounds per cubic yard and to average 0.24 pound per cubic yard (table 82). The sample showing 1.68 pounds of monazite per cubic yard came from a locality just south of the city of Chesterfield, Chesterfield County, in an area where several samples seem to have about twice as much monazite as the regional average for the Tuscaloosa.

The amount of monazite in the sedimentary rocks was thought by Dryden to be uninfluenced by the grain size of the sediments, and he presented evidence to show that coarse sands are not notably enriched in monazite (Dryden, 1958, p. 419). Radioactivity in the Tuscaloosa Formation was, however, found by Schmidt (1962, p. 36) to be notably greater in gravelly layers, particularly in basal gravel, than in the formation as a whole. Inasmuch as the radioactivity is attributed mainly to monazite, it would seem that Schmidt's observations discount the conclusion reached by Dryden that the amount of monazite is unrelated to the size of particles in the sediment.

TABLE 82.—*Inferred amount of monazite in the Tuscaloosa Formation in South Carolina*

[Modified from Dryden (1958, p. 401–405)]

	Number of samples	Inferred tenor (lb per cu yd)		
		Min	Max	Avg
Vicinity of Dillon, Dillon County	1			0.01
Vicinity and north of Bennettsville, Marlboro County	22	0.01	1.25	.21
South of Chesterfield, Chesterfield County	45	.01	1.68	.28
Flat Creek area, Lancaster County	4	.02	.50	.18
Ridgeway, Fairfield County	1			.08
South of Camden, Kershaw County	25	.01	.93	.30
Darlington County	4	.01	.48	.15
Vicinity of Lucknow, Lee County	2	.3	.68	.49
Western part of Sumter County	2	.08	.1	.09
Richland County	14	.03	.65	.26
Lexington County	10	.03	.88	.36
Aiken County	13	.01	.45	.13
Average	143			.24

Regional variations in the amount of monazite in the Tuscaloosa Formation were attributed by Dryden (1958, p. 421–422) to original abundances of monazite in source areas from which the sediments were derived. He suggested that parts of the formation having greater than average amounts of monazite possibly came from broad and rich segments of the monazite belt in the western Piedmont. For most areas in South Carolina this assumption seems to be correct, but for one area another explanation may fit the observations a little better.

Samples having indicated tenors of about 0.5 pound of monazite per cubic yard and several samples having more than a pound per cubic yard, including the richest sample from the Tuscaloosa in South Carolina, were obtained by Dryden (1958, p. 421) from an area in northern Marlboro County and part of Chesterfield County in the present drainage basin of the Pee Dee River. The source of this above-average Tuscaloosa Formation was speculatively suggested by Dryden to have been the western belt of monazite-bearing rocks. Because the drainage leading to Marlboro County and Chesterfield County comes by way of the Yadkin River from a narrow and low-tenor part of the western belt, Dryden offered the explanation that in Tuscaloosa time a more easterly system of drainage brought monazite from richer and wider parts of the belt southwest of the segment now reached by the Yadkin. Had these relations existed, however, it would seem that more samples of the Tuscaloosa in Marlboro County and Chesterfield County should have above-average tenors. Actually the averages for the two counties are little different from the regional average. Possibly this area of above-average tenor received its sedimentary debris from a much nearer, but relatively small, source in monazite-bearing crystalline rocks. It is here suggested that the source may have been an unreported body of monazite-bearing rock in a projection of the eastern monazite belt of Mertie (1953, pl. 1). If the trend of the eastern belt is extended, it is found to pass close to the area of high-tenor samples in Marlboro County and Chesterfield County. A small local source in this extension, now possibly buried under Tuscaloosa Formation, might more satisfactorily account for a few high-tenor samples than a large, distant source.

The Tuscaloosa Formation in the area between Chesterfield County and Columbia in Richland County was the source of four samples having rather high amounts of monazite and was the source of 50 samples lean in monazite (Dryden, 1958, pl. 20). Included among the high-tenor samples were three from Kershaw County in the vicinity of Camden: a sample having 0.68 pound of monazite taken just southeast of Camden, one having 0.93 pound of monazite collected near Lugoff, and one having 0.83 pound of monazite from a point between Lugoff and Blaney. The fourth high-tenor sample came from Richland County at a locality about 10 miles east of Columbia. It contained an estimated 0.65 pound of monazite per cubic yard. The general pattern of low-tenor samples between Richland County and Chesterfield County indicates that no very rich source of monazite was available to the streams which deposited this part of the Tuscaloosa Formation. At present the drainage into this area just reaches the northeastern segment of the core of the western monazite belt, and mostly it does not cross known monazite-bearing rocks in the eastern belt except in the vicinity of Columbia (Mertie, 1953, pl. 1). Evidence is not very clear as to the probable source of the monazite, but it seems to favor Dryden's interpretation that the monazite was brought from the western belt.

The Broad River and Saluda River join at Columbia to form the Congaree River which, about 35 miles downstream, is entered from the north by the Wateree River. Below this junction the stream flows to the Atlantic Ocean and is known as the Santee River. Drainage basins of the Broad River and Saluda River encompass most of the core of the western monazite belt and are underlain by the greatest area of monazite-rich crystalline rocks of any streams in the Piedmont. This system of drainage doubtless does not exactly match drainage patterns active in Tuscaloosa time; however, the fact that sedimentary rocks of the Tuscaloosa Formation exposed at and southwest of Columbia are richer in monazite than average Tuscaloosa in the State may indicate a similar drainage pattern in the past (Dryden, 1958, p. 442). Doubtless most of the monazite in this part of the formation was derived from the core of the western belt, but some is locally derived from granitic rocks immediately underlying the Tuscaloosa, a condition apparently observed by Schmidt (1962, p. 35–36) at Long Creek, which is a tributary to Twelvemile Creek in Lexington County, and near McTier Creek in northern Aiken County. There the base of the Tuscaloosa is composed of very radioactive gravelly sand containing small angular pebbles of blue-gray quartz similar to vein material in underlying granite. The granite was less radioactive than the gravel, but it was very likely the source of monazite in the gravel.

The sedimentary rocks in the Tuscaloosa Formation exposed south and southwest of Columbia were observed by Dryden to be richer in monazite than exposures of the formation elsewhere in the State. Tenors between 0.40 and 0.88 pound of monazite per cubic yard were estimated by Dryden (1958, pl. 20) for four samples of the Tuscaloosa in Lexington County, and the average tenor of 10 samples from the county is about 50 percent greater than the State average for the formation (table 82). These estimates are supported by the results of a natural gamma aeroradioactivity survey of this part of South Carolina (Schmidt, 1961). Areas underlain by Tuscaloosa Formation in Lexington County and northern Aiken County were found by Schmidt to be much higher in radioactivity than Tuscaloosa exposed farther south and west in Aiken County (Schmidt, 1962, p. 36). Seemingly, the greatest concentration of monazite now known in the Tuscaloosa Formation is in and west of the area presently reached by the Broad River and Saluda River. Possibly an earlier system of drainage from the core of the western monazite belt emptied at this part of the Tuscaloosa strand and deposited most of the monazite present in the formation.

Good evidence shows that the amount of monazite in the Tuscaloosa Formation declines southward across Aiken County and continues to decline in Georgia. This decline is shown by the estimates of tenor prepared by Dryden (1958, p. 404–405), where it is seen that the average tenor for the county is only 0.13 pound of monazite per cubic yard, in contrast to the State average of 0.24 pound (table 82). The decline is also indicated by the map of aeroradioactivity, which shows that the formation gave 700–1,300 counts per second in Lexington County and northern Aiken County but only 400–700 counts per second elsewhere (Guillou and Schmidt, 1960, p. B120; Schmidt, 1961).

Other writers have also indicated that the Tuscaloosa Formation in Aiken County is lean in monazite. Concentrates from several test wells in clay deposits in the formation were examined by W. B. Lang in the 1930's, but monazite was found in only one (Lang and others, 1940, p. 35). It came from a well 1.5 miles south of Langley on the south side of Horse Creek. The monazite occurred in material 45–46 feet below the collar of the well. In this interval the material contained a mixture of 75–80 percent of mica and 20–25 percent of white clay and quartz with some staurolite, tourmaline, zircon, sillimanite, monazite, ilmenite, and magnetite. White sand and clay of the Tuscaloosa Formation in the bed of Holley Creek were said by Kline, Griffith, and Hansen (1954, p. 10) to be relatively free of heavy minerals and to contain but scant monazite.

DEPOSITS OF TERTIARY AGE

The Tertiary sedimentary rocks in the Coastal Plain of South Carolina unconformably overlie formations of Cretaceous age and locally transgress onto pre-Cretaceous crystalline rocks. The Tertiary formations dip gently southward and strike eastward (Cooke, 1936, pl. 2). They are extensively mantled by very gently dipping deltaic, estuarine, or marine nearshore deposits of Pleistocene age. Seven Tertiary formations are described in South Carolina (Cooke and MacNeil, 1952, p. 20), but only four have as yet been reported to be monazite bearing. These are the Black Mingo Formation of the Wilcox Group, the Congaree Formation and the McBean Formation of the Claiborne Group, and the Barnwell Formation of the Jackson Group.

The nomenclature used by Cooke (1936, pl. 2) on his map of the Cretaceous and Tertiary formations of South Carolina was revised by Cooke and MacNeil (1952, p. 21–24) in a discussion of Tertiary stratigraphy of the State. Cooke and MacNeil introduced the term "Congaree Formation" for deposits of early Claiborne age in South Carolina, which had theretofore been mapped as McBean Formation, and they stated that a large part of the sedimentary rocks previously mapped as Barnwell Sand of Cooke proved upon reinvestigation to be Congaree also. Inasmuch as the revised terminology was not accompanied by a new map to show the effect of the change, it is not possible to relate the sparse data on monazite to the new terminology. In the following review the monazite-bearing sample localities are referred to Cooke's geologic map of 1936, on which the Black Mingo Formation, McBean Formation, and Barnwell Sand of Cooke are referred to the Eocene. The Black Mingo Formation of Cooke (1936, p. 41) is made up of gray to black brittle clay or shale, sandy shale, and sand. The McBean Formation of Cooke (1936, p. 56) consists mainly of fine to medium sand and thin beds of glauconitic marl, clay, and limestone. The Barnwell Sand of Cooke (1936, p. 89–90) transgresses northward unconformably over older formations and consists principally of fine to coarse reddish pebbly sand and massive orange sand. Because the McBean and Barnwell of Cooke are widely monazite bearing, it is here inferred that the Congaree Formation of Cooke and MacNeil also contains monazite.

Concentrates from these formations were reported to consist of dominant ilmenite and leucoxene with which are associated variable amounts of zircon, rutile, monazite, staurolite, kyanite, sillimanite, and tourmaline (Dryden, 1958, p. 393).

A sample from an exposure of the Black Mingo Formation of Cooke was estimated by Dryden (1958, p. 405) to contain 0.17 pound of monazite per cubic yard. The exposure is about 4 miles north of Eastover in Richland County.

Amounts of monazite from five samples from the McBean Formation of Cooke were inferred by Dryden (1958, p. 405) to have the following tenor:

	Tenor (lb of monazite per cu yd)
Calhoun County:	
Near Beaver Creek	0.83
Lexington County:	
North of Swansea	.48
Bull Creek south of Swansea	1.73
Orangeburg County:	
North Fork Edisto River near North	.43
Aiken County:	
Near Salley	.02
Average	.70

The high average tenor was attributed by Dryden (1958, p. 424) to concentration of the monazite in the lower part of the McBean by the reworking of materials from the Tuscaloosa. Dryden inferred that high tenors might be expected to persist laterally for considerable distances near the contact between the two formations owing to the regularity of bedding in the McBean. Possibly the monazite content of the McBean tends to be more regular than the grab samples show. The Bull Creek locality south of Swansea in Lexington County, where a very high-tenor sample was taken by Dryden, is in an area of moderately high natural radioactivity, giving 500–700 counts per minute (Schmidt, 1961, map). An almost identical radioactivity was measured over the Salley area in Aiken County, where a sample from the McBean was estimated to contain only 0.02 pound of monazite.

Surface sampling by the U.S. Bureau of Mines of the McBean Formation of Cooke exposed on ridges in the vicinity of Holley Creek and Town Creek in Aiken County was said to have shown fair to good concentrations of monazite, but the tenors of the samples were not reported (Kline and others, 1954, p. 14–15).

The Barnwell Sand of Cooke was sampled at 14 localities in South Carolina by Dryden (1958, p. 405). He estimated that these samples contained from 0.01 to 1.87 pounds of monazite per cubic yard and averaged 0.33 pound:

	Tenor (lb of monazite per cu yd)
Lexington County:	
Near Edmund	0.48
South of Edmund	.13
Aiken County:	
Near Wagener	.28
South Fork Edisto River east of Aiken	1.87
	.83
8 miles east of Aiken	.18
4 miles east of Aiken	.28
5 miles north of Aiken	.05
8 miles northeast of Aiken	.16
South of Eureka	.23
Eureka	.13
Edgefield County:	
Vicinity of Trenton	.01
East of Johnston	.04
Saluda County:	
Ridge Spring	.05
Average	.33

The sample having the highest tenor was collected in Aiken County at an exposure on the South Fork Edisto River about 11 miles east of the city of Aiken, in an area of low to intermediate radioactivity (Schmidt, 1961).

In the area around Holley Creek and Town Creek, Aiken County, surface samples were said to have indicated fair to good concentrations of monazite in the Barnwell Sand of Cooke, but the tenors were not specifically reported (Kline and others, 1954, p. 14–15). Surface materials in the Holley Creek–Town Creek area are generally low in natural radioactivity (Schmidt, 1961). Dryden (1958, p. 422) reported that the area he sampled adjacent to the Savannah River and southward was about the leanest in monazite of any parts of the State that he examined. The apparent conflict between the statements of Kline, Griffith, and Hansen and the observations of Schmidt and Dryden probably results from lack of regional background for comparison in the report by Kline and associates. There is no obvious reason to believe that the formations in the Holley Creek–Town Creek area are significantly richer in monazite than the same formations elsewhere in the State. Evidence has been presented to show that they are not. Such evidence clearly indicate that equal or richer fluvial placers may be present in valleys northeast of Aiken County in the Coastal Plain in Lexington County and Richland County.

MARINE TERRACE PLAINS OF PLEISTOCENE AGE

Thin marine deposits of Pleistocene age form terrace plains that extend inland for distances of 80 or

90 miles from the present coast of South Carolina (Cooke, 1936, p. 5–9, 130–154). They occupy about two-thirds of the area of the Coastal Plain. At many places the inner margin of the Pleistocene marine deposits is rather obscure owing to erosion of the highest terrace and to lack of relief between the terrace and the other sedimentary rocks inland from it. The terrace plains were interpreted by C. W. Cooke to have been formed by marine wave action in a succession of advances and retreats of the sea during the Pleistocene epoch. According to Cooke's concept the coastal region was warped downward at the close of Pliocene time and inundated by the sea as far inland as the highest and oldest terrace, which is found at an altitude of 270 feet above present sea level. Wave action along the shoreline of maximum advance created wave-cut and wave-built features of which remnants are still preserved. As the sea retreated the exposed plain was eroded. A new advance of the sea reached less inland, and another line of wave-formed features defined a second shore at an altitude of about 215 feet. Fresh layers of clay, sand, and gravel were deposited and covered the flooded part of the plain. Another retreat of the sea followed by other advances and retreats led to the formation of seven shore lines during the Pleistocene epoch. Remnants of these features are preserved at approximately the following heights, in feet, above present sea level: 270, 215, 170, 100, 70, 42, and 25 (Cooke, 1936, p. 130).

Seven formations corresponding to the seven high stages of the sea were recognized in South Carolina by Cooke (1936, p. 130–154). The inland edge of each formation was the shore of the sea and its estuaries at the given height. The seaward edge of the formation is taken as the shoreline of the next younger formation, and the surface of the formation is a terrace or plain between the defining shores. Names of the formations from oldest to youngest and approximate altitudes of the shorelines were given by Cooke (1936, p. 130):

Formation	*Altitude (feet)*
Brandywine	270
Coharie	215
Sunderland	170
Wicomico	100
Penholoway	70
Talbot	42
Pamlico	25

These Pleistocene formations are composed mainly of sand and clay. The sand tends to be finer in the younger formations than in the older formations and was thought by Cooke to have been washed out of older formations by currents that were too weak to transport coarse-grained debris. Very little sedimentary material was carried as far out to sea as the present coast; hence, deposits of pre-Pleistocene age are exposed near the present shore, and the Pleistocene formations in South Carolina are nowhere very thick.

Cooke's ideas have subsequently been challenged by Flint (1940, p. 757–785), Mertie (1953, p. 13–15), and others, and detailed work in the early 1960's in parts of South Carolina indicated that some revision in interpretation was needed (Colquhoun, 1962). In a review of the literature and a report on reconnaissance study of the Pleistocene sediments and surface features of the Atlantic Coastal Plain, Flint (1940, p. 757–785) concluded that the seven strandlines recognized by Cooke were not certainly demonstrated and that the deposits up to an altitude of at least 100 feet formed under marine conditions. Flint thought that at least two former shorelines were distinctly recognizable.

The Pleistocene terrace plains were thought by Mertie (1953, p. 13–15) to have received terrigenous sediments, mainly deltaic and estuarine deposits, which were laid down over older sediments that had been reworked by the sea. Ocean currents and waves did not generally affect the terrigenous sediments. In Mertie's opinion the coast was under more or less continuous epeirogenic uplift throughout the successive glacial and interglacial oscillations of the sea. In the absence of strong littoral sorting, beach placers failed to form.

Colquhoun's observations indicate a very complex interrelation between fluvial and marine deposition of the Pleistocene formations (Colquhoun, 1962, p. 73–75). None of this work has led to a revised map of the Pleistocene formations in South Carolina, and until such a map is available, reference will continue to be made to Cooke's map (1936, pl. 1).

Sediments at the present land surface of the Pleistocene marine terrace plains are lean in monazite. The amount of monazite in Coastal Plain formations of Pleistocene age in Georgia and South Carolina was reported by Mertie (1953, p. 15) to range from less than 1 to 9 percent of the concentrate, with concentrates making up only 0.01–0.1 percent of the sedimentary rock. Pleistocene formations in Calhoun, Orangeburg, Dorchester, Colleton, Bamberg, Barnwell, Allendale, and Hampton Counties, S.C., were found by Schmidt (1962, p. 35–38) to have less radioactivity than older deposits on the Coastal Plain. Dryden (1958, p. 406, pl. 20) examined 18 concentrates from Pleistocene sediments in the State and observed monazite in 17. The inferred average tenor was only 0.19 pound of monazite per cubic yard. When the locations of the 18 samples are plotted on Cooke's (1936, pl. 1) map of the Pleistocene deposits, it is seen that 11 samples came from formations in the marine terrace plains or estuarine extensions up the valleys of major streams, and 7 came from outlying deposits on old formations in the Coastal Plain northwest of the Brandywine terrace. Samples from the marine terrace plains have a low inferred average tenor of 0.11 pound of monazite per cubic yard, whereas samples from outlying areas northwest of the Brandywine terrace contain nearly three times as much monazite:

	Tenor (lb of monazite per cu yd)
Marine terrace plains and estuarine deposits	
Marlboro County:	
Brandywine Formation north of Bennettsville	0.13
Penholoway Formation south of Bennettsville	.21
Wicomico Formation south of Bennettsville	.05
Dillon County:	
Wicomico Formation east of Dillon	.00
Wicomico Formation southwest of Dillon	.05
Florence County:	
Penholoway Formation southeast of Florence	.10
	.21
Chesterfield County:	
Wicomico Formation southeast of Chesterfield	.02
Darlington County:	
Coharie Formation northwest of Hartsville	.08
Kershaw County:	
Brandywine Formation southeast of Camden	.16
Richland County:	
Coharie Formation at Columbia	.25
Average	.11
Pleistocene sediments northwest of the Brandywine terrace	
Chesterfield County:	
Southwest of Chesterfield	0.18
	.38
Lexington County:	
West of Edmund	.45
Southwest of Edmund	.03
Aiken County:	
Near Eureka	.33
North of Aiken	.13
East of Aiken	.55
Average	.29
Average, all samples	0.19

The mineralogical composition of concentrates from the Pleistocene deposits was said by Dryden (1958, p. 393–394, 424) to resemble the composition of concentrates from Cretaceous and Tertiary formations in that they lack epidote, garnet, and hornblende. They commonly consist of 50 percent or more of ilmenite and leucoxene and variable percentages of other minerals. In approximate order of average abundance the minerals are zircon, rutile, monazite, staurolite, kyanite, sillimanite, tourmaline, and spinel. At several places, pairs of samples from the Tuscaloosa Formation and overlying Pleistocene deposits were collected by Dryden, and the samples in a pair from a given locality were usually found to be very similar in tenors in monazite. This similarity was interpreted by Dryden to suggest that in these pairs of samples the sedimentary material of Pleistocene age was composed largely of reworked Tuscaloosa Formation.

Concentrates from alluvium in Coastal Plain reaches of trunk streams rising in the Blue Ridge or Piedmont contain epidote, garnet, and hornblende along with the other minerals found in Coastal Plain sediments (Dryden, 1958, p. 393–394). Epidote, garnet, and hornblende are also present in concentrates from the present beaches. The evidence does not show with certainty whether these minerals are absent in the Pleistocene deposits because the deposits were derived mainly from old formations devoid of epidote, garnet, or hornblende, or whether these minerals have weathered out of the Pleistocene sediments since they were deposited. In the Piedmont of South Carolina, however, Pleistocene alluvium of pre-Wisconsin age displays only barely perceptile reduction in epidote, garnet, and hornblende owing to weathering after deposition (D. W. Caldwell, written commun., 1954). To the writer the absence of these three minerals in the Pleistocene deposits most likely indicates that the Pleistocene sediments were mainly derived from Cretaceous and Tertiary formations.

The higher tenor in monazite of the Pleistocene deposits northwest of the Brandywine terrace compared to tenor in monazite of Pleistocene sediments southeast of the terrace coincides with observed seaward decrease in radioactivity of surface materials in the Coastal Plain. Such distribution in tenor seems more to be expected from sedimentary processes as interpreted by Cooke than from processes as interpreted by Mertie. The absence of epidote, garnet, and hornblende from Pleistocene sediments on marine terrace plains also fits well with Cooke's ideas but not with those of Mertie. Until systematic and detailed studies of these deposits are made, however, the sedimentary processes remain uncertain. Detailed studies are also needed before a correct evaluation can be made of possible placer deposits of monazite and other heavy minerals in the Pleistocene formations. No accounts have been published of heavy minerals in the spits, islands, and other depositional features

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strikingly shown by Cooke (1936, pl. 1) on marine terrace plains underlain by the Pamlico, Talbot, Penholoway, and Wicomico formations in South Carolina. Obviously such features need to be thoroughly examined before the possibility of workable placers can be evaluated. Placers workable for monazite alone, however, are not to be expected, although ilmenite deposits from which monazite might be recovered as a byproduct are a possibility.

STREAM SEDIMENTS OF QUATERNARY AGE

Sediments in the valleys of the present streams of the Coastal Plain are Quaternary in age. Major streams entering the Coastal Plain from the Piedmont were depicted by Cooke (1936, pl. 1) to have along their valleys various flood-plain and terrace deposits related to Pleistocene formations he recognized on the marine terrace plains. Rivers rising on the Coastal Plain are shown as occupying valleys filled with Pleistocene formations appropriate for the altitudes reached by the flood plains. Valleys of streams rising in the Coastal Plain derive their fill from adjacent unconsolidated sediments, but valleys of trunk streams seem to have gotten their sediments chiefly from the Piedmont and Blue Ridge and did not receive much from the Coastal Plain (Dryden, 1958, p. 425). Suites of heavy minerals from valley deposits along streams rising in the Coastal Plain lack the notable amounts of epidote, garnet, and hornblende present in concentrates from sediments in the Coastal Plain segments of the valleys of trunk streams rising in the Blue Ridge or Piedmont (Kline and others, 1954, p. 17; Dryden, 1958, p. 425). If interstratal solution had removed the less stable minerals in the Pleistocene formations on the marine terrace plains, then solution should have been equally effective in removing the same kinds of minerals in sediments in the valleys of trunk streams providing that the sediments in the main valleys are time equivalents of formations on the terrace plains.

Monazite-bearing concentrates were panned in the late 1940's by Mertie (1953, pl. 1, p. 15) from sediments in streams on the Coastal Plain of South Carolina. The amount of monazite was reported to be small, being 1–9 percent of concentrates that constituted only 0.01–0.1 percent of the sediment, but monazite was present in 36 out of 38 samples. If the locations of Mertie's samples are compared to the Pleistocene formations as shown by Cooke (1936, pl. 1), it is seen that each of the Pleistocene formations was the proximate source of some monazite-bearing stream sediment:

County	Formation	Number of monazite-bearing samples of stream sediment
Calhoun	Sunderland	2
	Brandywine	1
Clarendon	Wicomico	1
Orangeburg	Wicomico	1
	Sunderland	5
	Coharie	3
	Brandywine	1
Dorchester	Pamlico	2
	Wicomico	1
	Sunderland	1
Berkeley	Pamlico	2
	Talbot	3
	Penholoway	2
Charleston	Pamlico	1
	Talbot	1
Georgetown	Pamlico	3
	Talbot	4
Williamsburg	Penholoway	2
Total		36

The Calhoun County localities are on tributaries to Halfway Swamp. In Clarendon County, monazite was found in a small stream between Jacks Creek and the Santee River. Cooper Swamp and streams west to the South Fork Edisto River in southwestern Orangeburg County were shown by Mertie to contain monazite, and in the eastern part of the county, monazite was present in concentrates from tributaries to Four Hole Swamp, Sandy Run, and the Santee River. Streams in Dorchester County that were sources of monazite-bearing concentrates are Cattle Creek, Four Hole Swamp, and the Ashley River. In Berkeley County, monazite was found along Cypress Swamp, Back River, Biggin Swamp, East Branch, and short tributaries to the Santee River. Tributaries to Goose Creek and the Wando River in Charleston County yielded monazite, as did the Sampit River and tributaries to the Black River in Georgetown County. Farther upstream along the Black River, tributaries in Williamsburg County also were the source of monazite-bearing concentrates.

Present sediments in the valley of Rocky Creek about 5 miles west-northwest of Lexington in Lexington County were reported by Mertie (1953, p. 13) to contain about 0.5 pound of monazite per cubic yard. Granite exposed in the bed of the stream is devoid of monazite; thus, Cretaceous or Tertiary formations overlying the granite are the probable source of the monazite.

Sediments in the valleys of streams around Aiken in Aiken County were found to be monazite bearing by

Mertie (1953, p. 13) during the course of work in the summer of 1951. Toward the close of the year interest began to develop in these deposits, particularly in those on Holley Creek, Town Creek, and Horse Creek. A program to evaluate placers along the valleys of Holley Creek and Town Creek and the Holley Creek delta in the valley of the Savannah River was begun by the U.S. Bureau of Mines in December 1951 (Kline and others, 1954, p. 4–5). The valleys of Holley Creek and Town Creek were estimated, on the basis of results from 21 widely spaced churn-drill holes out of 45 sunk, to contain 66 million cubic yards of alluvium having about 40,000 short tons of monazite (Kline and others, 1954, p. 6):

	Tenor (lb of monazite per cu yd)	*Reserves (1,000 short tons)*
Monazite	1.21	40
Rutile	1.67	55
Zircon	1.99	66
Ilmenite	4.82	160
Staurolite	6.40	212
Kyanite	.73	24

The potential placer ground has an area of about 2,230 acres and an average depth of 18.4 feet. The base of the placer is a relatively barren white sand and clay at depths ranging from 10 to 40 feet below the surface of the flood plain. Total length of the placer area along both streams is 16 miles, and throughout this length the flood plains range in width from 225 to 3,300 feet.

Throughout their length the streams were reported to flow on sedimentary rocks of the Tuscaloosa Formation (Kline and others, 1954, p. 11–13), but the prominent ridge between Holley Creek and Town Creek is capped by the McBean Formation, and a few miles to the south of the two streams the McBean and Barnwell Formations cover the Tuscaloosa. Pleistocene terraces are present in the valleys from the Brandywine terrace at an altitude of 270 feet to the Wicomico at an altitude of 100 feet, and blown sand covers the ridges and forms dunes locally. Spot samples of the Tuscaloosa, McBean, and Barnwell Formations by Kline, Griffith, and Hansen (1954, p. 14–15), supported by earlier reports on heavy minerals in wells in these formations (Lang and others, 1940, p. 32–40) show that monazite is more abundant in this area in the McBean and Barnwell Formations than in the Tuscaloosa. It is inferred that the Tuscaloosa is less important as a source for monazite in Holley Creek and Town Creek than is the McBean and Barnwell. They also postulate that Holley Creek is actively degrading and that erosion is more conducive to the formation of fluvial placers than rapid aggradation.

Alluvium in Holley Creek upstream from the valley of the Savannah River was said to give concentrates with a restricted suite of heavy minerals consisting of the most stable species, whereas concentrates from alluvium in the flood plain of the Savannah River at the mouth of Holley Creek contain a striking display of unstable minerals (Kline and others, 1954, p. 16–17). In Holley Creek proper, epidote is present in only trace amounts, as are magnetite and garnet, but in the delta of Holley Creek on the flood plain of the Savannah, epidote makes up 15 percent of the concentrate, and magnetite and garnet are even more abundant. Zircon, monazite, rutile, and staurolite are much more common in concentrates from the valley of Holley Creek than they are in concentrates from the Savannah River flood plain. About equal amounts of ilmenite, kyanite, and tourmaline are in concentrates from the two sources. The composition of concentrates from each area shows the general relations (table 83). The suite of heavy minerals in the delta of Holley Creek has been influenced by unstable minerals added from the distributive province of the Savannah River.

TABLE 83.—*Mineralogical composition, in percent, of monazite-bearing concentrates from Holley Creek and the Savannah River, Aiken County, S.C.*

[Modified from Kline, Griffith, and Hansen (1954, p. 17). Symbol used: n.d., no data]

	Holley Creek (single hole)	Holley Creek and Town Creek (field composite concentrate from 24 holes)	Savannah River (single hole)
Monazite	4.3	5.8	2.2
Xenotime	.4	n.d.	.2
Epidote	----------	n.d.	15.2
Hornblende	Trace	n.d.	6.3
Garnet	----------	n.d.	2.1
Ilmenite	27.5	22.0	48.8
Magnetite	.1	----------	3.8
Quartz	16.0	20.0	17.0
Zircon	12.0	9.0	2.8
Rutile	9.8	8.0	2.5
Kyanite	2.0	3.5	----------
Staurolite	25.5	30.0	----------
Tourmaline	.2	1.5	----------
Total	97.8	99.8	100.9

Chemical analyses by the U.S. Bureau of Mines of monazite separates from the Holley Creek area show 5.08 percent of ThO_2 and 0.54 percent of U_3O_8 (Kline and others, 1954, p. 18–20; Kauffman and Baber, 1956, p. 6). The area was said by the Bureau to be suited to mining by either bucket-line or suction dredge. Estimated value of the total product based on prices of January 1954 was $0.40 per cubic yard for the heavy minerals and $0.19 for the gravel (Kline and others, 1954, p. 28).

The first large-scale mining of fluviatile placers for monazite and other heavy minerals in the Carolinas was begun in June 1955 by Marine Minerals, Inc., on Horse Creek about 10 miles southwest of Aiken in Aiken County (Lenhart, 1956, p. 62–63). Horse Creek is the next major tributary to the Savannah River upstream from Holley Creek, and in many respects the deposit resembles the placers on Holley Creek and Town Creek, except that parts of the valley of Horse Creek and its western tributaries reach granitic rocks that underlie the Tuscaloosa and younger formations. Most of the valley is eroded in the sedimentary rocks near the inner edge of the Coastal Plain, but the main stream above Graniteville and the head of Little Horse Creek expose crystalline rocks (Schmidt, 1962, p. 36).

The valley of Horse Creek has been described as a semiswamp covered with trees and brush and interrupted locally by old dams. The company was reported to have 18–20 million cubic yards of dredging ground on which it located a 6-cubic-foot bucket-line dredge capable of digging to a depth of 35 feet, but most heavy minerals occur at a depth of about 20 feet or less (Lenhart, 1956, p. 63). Another report dating from the early days of the operation stated that the dredge could mine about 2 million cubic yards of sediment a year of which about 1 percent was heavy sand (Crawford, 1958c, p. 1156).

The heavy sand was reported to be practically free of magnetite (Lenhart, 1956, p. 63–66). Five industrial minerals—monazite, rutile, ilmenite, zircon, and staurolite—were separated from the dredge concentrate in a dry plant on shore, and cleaned and screened sand and gravel were produced through an affiliated company. Actual output at Horse Creek is not known, but if the tenor in monazite at Horse Creek is on the same order as at Holley Creek, and 20,000–30,000 short tons of concentrate were produced per year, then the placer may have yielded about 1,200–1,500 short tons of monazite per year. Mining ceased in 1959.

Monazite from Horse Creek was analyzed by the U.S. Bureau of Mines and was reported to contain 5.07 percent of ThO_2 and 0.51 percent of U_3O_8, quantities almost identical to those in monazite from Holley Creek (Kauffman and Baber, 1956, p. 6).

Placers on Shaw Creek and the South Fork Edisto River in Aiken County were regarded by Perry (1957, p. 4) to equal in size and quality the Horse Creek deposit, but volumes and tenors were not described.

Monazite placers were reported by H. S. Johnson, Jr. (oral commun., 1959) to have been found on McTier Creek in northern Aiken County, and an aeroradioactivity high was measured over the area. Sand in McTier Creek was said to contain 1 percent of heavy minerals in which as much as one-third was monazite. Granite and sediments of the Tuscaloosa Formation exposed in the valley are monazite bearing (Schmidt, 1961).

Traces of monazite were reported by Shufflebarger (1958) to be in mineralogically complex concentrates from flood-plain sediments of the Wateree River south of Camden, Kershaw County. Both banks of the river for a distance of about 8 miles upstream from Sumters Landing are composed of sand, silt, clay, and organic matter which ranges in depth from 8 to 20 feet and contains from grass roots to bedrock an average of somewhat less than 1 percent of heavy minerals. The amount of heavy minerals was said to increase with increasing degree of coarseness of the sediment. Coarse and medium sand has from 4.1 to 14.2 percent of heavy minerals, and the silts and clay have from less than 0.1 to 3.4 percent. Ilmenite, epidote, hornblende, garnet, kyanite, staurolite, and tourmaline are the most common minerals. A little magnetite is present, and rutile, zircon, and monazite occur as traces.

COASTAL ISLANDS AND BEACHES

At many places along the South Carolina coast, monazite and other industrial minerals have been noticed, and at a few places, notably in the extreme southern part of the State, extensive drilling has been undertaken and the results published. Placer mining, however, has not been started. Reported occurrences of monazite on the coastal islands and beaches are summarized, starting in the northeast.

Sand along the shore and in dunes at Myrtle Beach, Horry County, was said to be monazite bearing (Jones, W. H., 1949a, p. 458). Concentrations of heavy minerals form black layers in the dunes.

Natural concentrates containing 80 percent or more of heavy minerals have been formed by wave and wind action on the islands of the South Carolina coast (Neiheisel, 1958a, p. 1). The concentrates range in length from 1 to 5 miles, in width from 20 to 150 feet, and in thickness from 3 inches to 3 feet. In order of decreasing abundance of heavy minerals the deposits are Bull Island, Capers Island, Isle of Palms, Edisto Island, Fripp Island, Dewees Island, and Hilton Head Island. Concentrates from these islands contain an average of 55 percent of ilmenite, 3 percent of rutile, 4 percent of leucoxene, 8 percent of zircon, and 1 percent of monazite accompanied by epidote, hornblende, staurolite, kyanite, garnet, tourmaline, and several other minerals in minor amounts.

At Bull Island, Charleston County, beds of black sand consisting of 80 percent heavy minerals were reported to be 1–3 feet thick and to have an average width of 70 feet over a stretch of backshore beach 3 miles long (Neiheisel, 1958a, p. 1–3). This deposit was estimated by Neiheisel to contain 150,000 short tons of heavy minerals composed of 63 percent of ilmenite, 2 percent of rutile, 4 percent of leucoxene, 10 percent of zircon, and 1.5 percent of monazite with accessory epidote, staurolite, hornblende, kyanite, tourmaline, garnet, and magnetite.

Capers Island in Charleston County contains natural concentrations of heavy minerals whose tenor and components were described as being similar to the deposit on Bull Island (Neiheisel, 1958a, p. 3). The Capers Island placers are in the upper foreshore. They extend for a length of 2 miles, have an average width of 50 feet, and range in thickness from 1 to 2 feet.

The oceanic side of the Isle of Palms, Charleston County, is lined with dunes and beach ridges parallel to the shore (Neiheisel, 1958a, p. 4–5; 1958b, p. 46–49). About 1,000 acres on the northern part of the island is covered by dunes which were estimated by Neiheisel to contain 850,000 short tons of heavy minerals in dune sands averaging 8 percent of heavy minerals. The largest concentrations of heavy minerals are in the lower dunes. Monazite makes up less than 1 percent of the concentrate from dune sand (table 84). A heavy-mineral deposit occurs 0.5 mile south of the northernmost end of the island and extends 1 mile southward along the beach. It is wedge shaped and tapers southward having an average width of 30 feet and a thickness of 3–6 inches. According to Neiheisel (1958a, p. 4–5), this placer is estimated to contain 15,000 short tons of heavy minerals of which 55 percent is ilmenite.

A beach on the northern part of Edisto Island, Charleston County, was said to contain natural concentrations of heavy minerals in the upper foreshore area for a length of 3 miles (Neiheisel, 1958a, p. 5). The placer is 10–40 feet wide and 2 inches to 2 feet thick. It consists of 65 percent of ilmenite, 3 percent of rutile, 6 percent of leucoxene, 12 percent of zircon, and 0.5 percent of monazite. Epidote and hornblende are not as common as they are on the islands to the north.

TABLE 84.—*Abundance of heavy minerals, in percent, related to average height of sand dunes on the Isle of Palms, Charleston County, S.C.*

[Modified from Neiheisel (1958, p. 46–51)]

	7-ft dunes	12-ft dunes	35-ft dunes
Ilmenite	40	35	31
Epidote	32	30	22
Hornblende	4	9	20
Zircon	8	6	6
Staurolite	4	6	5
Rutile	3	4	3
Leucoxene	4	5	4
Kyanite	2	2	4
Garnet	1	1	1
Tourmaline	1	1	1
Monazite, sillimanite, magnetite, hypersthene	1	1	2

Natural concentrates have formed on a 2-mile-long sector of the beach on Fripp Island, Beaufort County, from a point 0.5 mile south of the north end of the island (Neiheisel, 1958a, p. 6). The placer has an average width of 100 feet and ranges in thickness from 6 inches at its north end to 1 inch at the south. Mineralogical composition resembles the concentrates on Edisto Island.

Along the southernmost mile of beach on Dewees Island, Charleston County, heavy minerals have been naturally concentrated into shorter, thinner, and narrower deposits than the placers on Bull Island or Capers Island, but the mineralogical composition is similar (Neiheisel, 1958a, p. 4).

Hilton Head Island in Beaufort County was explored for heavy minerals in 1954 and 1955 by the National Lead Co. and the U.S. Bureau of Mines (Johnson, H. S., 1960, p. 2). The results of this exploration were compiled by McCauley (1960, p. 1–31), who presented a map showing the locations of the drill holes and detailed tables giving the mineralogical composition of the sands. The report is unique in its completeness compared to other published accounts of heavy minerals in the coastal sands of the Southern States. According to Mrs. McCauley's report the National Lead Co. drilled 545 holes and the Bureau drilled 265. To a depth of 10 feet the sand averaged 2.14 percent of heavy minerals where drilled by National Lead, and 20 percent of the holes were in sand that contained 3 percent or more of heavy minerals. In the area drilled by the U.S. Bureau of Mines the sand to a depth of 11.1 feet averaged 2.19 percent of heavy minerals, and 17 percent of the holes were in sand that had 3 percent or more of heavy minerals. Major heavy minerals in concentrates examined by the Bureau were 35.0 percent of ilmenite, 11.7 percent of zircon, 5.5 percent of rutile, and 1.43 percent of monazite. Apparently the best placers are along the north half of the beach and adjacent foredune areas where the sand averages 7.87 percent of heavy minerals. Estimates show at least 8 million short tons of heavy minerals in the drilled areas, which comprise about 18,000 acres.

Small concentrations of heavy minerals are known on Sullivans Island in Charleston County and Hunting Island and Pritchard Island in Beaufort County (Neiheisel, 1958a, p. 6). Monazite is practically absent at Sullivans Island.

The heavy fraction of sand from Folly Beach, Charleston County, was reported by Martens (1935, p. 1566, 1585) to contain a little monazite:

	Percent		Percent
Ilmenite	55	Tourmaline	1
Zircon	14	Garnet	1
Rutile	4	Collophane	1
Monazite	2	Leucoxene	2
Epidote	10	Sphene	Trace
Staurolite	4	Zoisite	Trace
Sillimanite	1	Hypersthene	Trace
Kyanite	1	Corundum	Trace
Hornblende	2		

An airborne radioactivity survey of the Atlantic Ocean beach between the mouth of the South Edisto River, S.C., and Cape Fear, N.C., disclosed abnormal radioactivity at six localities in South Carolina (Meuschke and others, 1953). No ground checks of the sources of the radioactivity were made, but it was assumed that the radioactive sources are minerals that occur in black sands found locally on this part of the coast. Probably monazite is the main radioactive mineral, but it was not specifically mentioned. The six anomalously radioactive areas, all in Charleston County, are the area immediately northeast of the mouth of the North Edisto River; Folly Beach; Isle of Palms; Bull Island; west of Cape Romain; coast southwest of the mouth of the Santee River. The beach and dunes on Wadmalaw Island in Charleston County produced about 30 aeroradioactivity highs which have been interpreted as probably resulting from surficial concentrations of monazite (Meuschke, 1955).

The observations on the distribution of monazite, or of anomalously radioactive areas along the Atlantic beaches of South Carolina seem to indicate that monazite is more common on the part of the coast southwest of the mouth of the Santee River than it is to the northeast of that outlet. This stream, and its ancestral courses, may be the greatest single source of detrital monazite on the Atlantic seaboard. The large resources of monazite on Hilton Head Island, as proved by extensive drilling, are probably only a very small part of those in the coastal islands south of the outlet of the Santee River.

SOUTH DAKOTA

Minor accessory monazite occurs in lithium- and tin-bearing pegmatites in the Harney Peak uplift in the southern Black Hills and in the Nigger Hill uplift in the northern Black Hills of South Dakota (O'Harra, 1902, p. 67; Hess, 1909, p. 149; Ziegler, 1914a, p. 268; Connolly, 1925, p. 23; Connolly and O'Harra, 1929, p. 231; Rothrock, 1944, p. 58). The reported occurrences are in the southern Black Hills pegmatite district, Pennington and Custer Counties, and the Tinton district, Lawrence County, in the Nigger Hill uplift. Very little specific discussion of the geologic relations of the monazite in the crystalline rocks has yet been given, and this fact reflects the scarcity of the mineral in these localities (Page and others, 1953).

Small amounts of monazite were said to have been found in the gold and tin placers in the Harney Peak and Nigger Hill uplifts. The cycles of placer formation in the Black Hills were said by Connolly (1933, p. 6–9) to have begun with the formation of gold placers in Cambrian time during a period of weathering and erosion following the deposition of lode deposits in Precambrian time. As a result of later erosion, only small remnants of the Cambrian placers are left. Late Tertiary or early Quaternary erosion stripped Paleozoic and Mesozoic sedimentary rocks from the Black Hills dome and formed placer deposits now seen as high benches. Increasingly younger placers formed on low benches and in the present channels of the streams. Accompanying the gold in the placers are small amounts of monazite, cassiterite, columbite-tantalite, wolframite, scheelite, beryl, garnet, magnetite, hematite, ilmenite, tourmaline, and barite. Monazite has not been saved during the mining of the gold and tin.

In the Harney Peak area, small amounts of detrital monazite have been reported from placers along Spring Creek and its tributaries in Pennington County (Ziegler, 1914b, p. 192). A concentrate from a cassiterite placer near Tinton, Lawrence County, was said by Day and Richards (1906b, p. 1214–1215) to have the following mineralogical composition:

	Pounds per short ton		Pounds per short ton
Magnetite	504	Cassiterite	66
Ilmenite	128	Dolomite	20
Garnet	82	Other minerals	80
Hematite	804	Gold	Present
Monazite	6		
Zircon	20	Total	1, 998
Quartz	288		

The degree of concentration was unspecified. Seemingly monazite is much less common in the tin placers in South Dakota than in other tin deposits. There are no analyses to show the amount of thorium oxide in the South Dakota monazite.

TENNESSEE

Accessory monazite occurs in a boulder of gray coarse-grained granite in a boulder bed in the northern arenite sequence of the Ocoee Series exposed 3–4 miles west of Tuckaleechee in Blount County, Tenn. (Carroll and others, 1957, p. 185).

Monazite-bearing fossil placers were reported by R. A. Laurence (written commun., 1951; oral commun., 1960) at several places in Tennessee. They occur in the Precambrian Ocoee Series in the southeastern part of Tennessee near the border with North Carolina; in the basal sand of the Devonian Chattanooga shale, but specific localities have not been cited; and in a Paleocene sinkhole at Indian Mound, Stewart County. In 1957 some prospecting was done in Benton, Carroll, and Henderson Counties for rare-earth-bearing heavy minerals associated with detrital ilmenite in probable marine deposits in the Cretaceous McNary Sand (Eng. and Mining Jour., 1957; Gillson, 1958, p. 103). Terrace deposits along the Cumberland River in Stewart County were reported to be monazite bearing (R. A. Laurence, written commun., 1951). Alluvial deposits in the valley of the French Broad River and some of its tributaries in Sevier and Cocke Counties were said by R. A. Laurence (oral commun., 1960) to contain monazite. Three samples of Recent sand from the bed of the Mississippi River at Memphis, Shelby County, were examined by Russell (1937, p. 1316–1325) and found to have small amounts of monazite.

TEXAS

Rare-earth minerals were discovered in a large body of pegmatite at Baringer Hill, Llano County, in 1887, and they were intermittently quarried until 1907, principally by W. E. Hidden who was an important figure in the Carolina monazite industry (Hess, 1908; Landes, 1932; Sellards and Evans, 1943, p. 376). The locality, now flooded by Lake Buchanan, was worked for its yttria minerals, of which many varieties were found, but detailed lists of the minerals found at Baringer Hill do not include monazite. Monazite was also unreported from other crystalline rocks of Texas.

The heavy minerals in 31 samples of sedimentary rocks of Eocene, Oligocene, and Miocene age in Fayette County were studied by Bowling and Wendler (1933, p. 536–540). Monazite was found to be a scarce accessory mineral in 7 of the 31 samples and was questionably identified in another sample. The mineralogical composition of the eight monazite-bearing samples, which come from the vicinity of La Grange, Flatonia, and Ledbetter, is shown in table 85. Most of the material studied was sand, but reworked silicic tuffs and bentonite are a large part of the Catahoula section, and the basal Oakville, which unconformably overlies the Catahoula, commonly contains volcanic ash mixed with well-rounded quartz grains and coquina debris. Apparently these sediments were deposited under fluvial, lagoonal, and littoral conditions. Nothing in the descriptions relates the monazite to the volcanic debris. Probably the monazite was derived from the reworking of older sedimentary rocks in which it occurs as detrital grains.

TABLE 85.—*Mineralogical composition of monazite-bearing concentrates from sand of Tertiary age exposed in Fayette County, Tex.*

[Modified from anyalyses by Wendler (in Bowling and Wendler, 1933, p. 540). Symbols used: A, 20–80 percent; C, 10–20 percent; R, 1–10 percent, P?, possibly present; Ab, absent]

	Basal Oakville		Catahoula				Upper Jackson	
	1	2	3	4	5	6	7	8
Magnetite	A	A	A	A	A	A	A	A
Limonite	A	C	A	A	Ab	A	C	A
Zircon	C	A	A	C	C	A	A	A
Ilmenite	C	C	Ab	C	A	C	C	C
Pyrite	C	Ab	Ab	Ab	C	Ab	Ab	Ab
Leucoxene	C	C	Ab	C	C	C	C	C
Kyanite	C	C	Ab	R	Ab	C	C	C
Tourmaline	R	R	Ab	Ab	Ab	R	C	R
Rutile	R	Ab	R	R	R	R	R	R
Epidote	Ab	C	R	R	Ab	C	Ab	P?
Staurolite	R	Ab	Ab	R	R	R	R	R
Monazite	R	R	R	R	R	R	P?	R
Biotite	R	Ab	R	C	Ab	C	R	R
Muscovite	Ab	Ab	Ab	Ab	Ab	C	Ab	Ab
Garnet	R	Ab	Ab	R	Ab	Ab	Ab	Ab
Anatase	Ab	Ab	Ab	Ab	R	R	Ab	Ab
Sphene	Ab	Ab	Ab	Ab	Ab	R	Ab	Ab
Brookite	Ab	Ab	Ab	Ab	Ab	P?	Ab	Ab

1. 7 miles north-northeast of La Grange.
2. 1 mile south of Flatonia.
3. 10 miles southeast of Ledbetter on Cummins Creek.
4–5. Locality not given on authors' index map, p. 546.
6. 4 miles southwest of La Grange.
7–8. 4 miles south of Ledbetter.

The heavy minerals in Recent river and beach sands of Texas were studied by Bullard (1942, p. 1022). He found that the Rio Grande, Nueces, and Trinity Rivers lacked monazite. Monazite-bearing concentrates, however, were obtained from sand of the San Antonio River near McFaddin, Refugio County; Colorado River 3 miles south of Matagorda, Matagorda County; Brazos River at the mouth of the old channel southeast of Freeport, Brazoria County; and Neches River southwest of Lufkin, Angelina County (table 86). Concentrates from the Colorado River contain green hornblende in some abundance, but this mineral and the pyroxenes, typical of the sediment in the Rio Grande, are lacking in the other streams. Stable

TABLE 86.—*Mineralogical composition, in percent, of monazite-bearing concentrates from river sand in southeastern Texas*

[Modified from Bullard (1942, p. 1026, table 1). Symbol used: --, absent]

	San Antonio River	Colorado River	Brazos River			Neches River
Apatite	1	1	1	1	2	--
Black opaque minerals	54	45	46	64	45	50
Epidote	2	5	1	1	1	1
Garnet	2	4	14	7	12	1
Hornblende	1	20	1	--	--	--
Iron oxides	4	1	2	1	2	10
Kyanite	2	--	2	--	2	2
Leucoxene	16	7	12	6	12	9
Monazite	2	1	1	2	1	3
Rutile	2	--	--	2	2	3
Staurolite	3	1	5	1	2	6
Tourmaline	5	1	2	1	2	1
Zircon	10	14	13	14	14	11
Enstatite	--	--	1	--	--	1
Hypersthene	--	--	--	--	1	--
Brookite	--	--	--	--	1	1

resistate minerals are characteristic of the suites reported from the San Antonio, Brazos, and Neches Rivers.

Heavy minerals were found by Bullard (1942, p. 1029–1034) to be very abundant in the beach sands of the Texas coast. Crude banding of the sands is very common. The dark layers show the concentration of heavy minerals on the beach by the surf and in dunes by the wind. Northeastward from the mouth of the Rio Grande along the beach of Padre Island the heavy sands give way rather abruptly from suites characteristically rich in basaltic hornblende and other minerals common to fluvial concentrates from the Rio Grande, to those typical of the Colorado, with the addition of monazite in many samples (table 87). Near the mouth of the Nueces River there is an increase in the relative abundance of the resistate minerals. Similar increases in the relative abundance of the resistate minerals occur near the mouths of the San Antonio and Brazos Rivers. Apparently the distribution of the heavy minerals is influenced by a southward-flowing longshore current.

Monazite in the beach sands is greenish-yellow to yellow round or irregular ellipsoidal grains. It is more common in the southern beach sands than in sand on Galveston Island (Bullard, 1942, p. 1034).

UTAH

Monazite-bearing titaniferous sandstone layers of Late Cretaceous age have been observed at three areas in Utah (Dow and Batty, 1961, p. 1–3). These sandstone layers are fossil placer similar to those known in Arizona, Colorado, Montana, New Mexico, and Wyoming. Seven areas of titaniferous sandstone are known southeast of Emery, Emery County; 1 deposit is on the southwest flank of the Henry Mountains in Garfield County; and 14 deposits are on the Kaiparowits Plateau in Garfield and Kane Counties south of Escalante. Sixteen of the deposits were reported to contain an estimated 1 million short tons of titaniferous sandstone having an average grade of 0.09 percent of $eThO_2$ (Dow and Batty, 1961, p. 1).

The seven areas of titaniferous sandstone near Emery crop out along tributaries to the Muddy River about 6 miles southeast of Emery where the streams breach the Coal Cliffs (Dow and Batty, 1961, p. 14). Five outcrops are probably part of the same fossil placer, and the other two are parts of parallel but separate lenses of titaniferous sandstone. The sandstone consists of quartz, feldspar, titanium minerals, zircon, magnetite, and monazite cemented by hematite and carbonates. The fossil placers occur near the base of the Ferron Sandstone Member of the Mancos Formation. They have an average thickness of 5 feet and contain 0.1 percent of $eThO_2$.

The fossil placer on the southwest flank of the Henry Mountains is on the southwest side of Mount Hillars 57 miles by road south of Hanksville (Dow and Batty, 1961, p. 14–16). It occupies a channel near the top of the Ferron Sandstone Member, but in composition it resembles the cemented black sand near Emery. In exposed size the fossil placer is 1,560 feet long, as much as 100 feet wide, and averages 3 feet in thickness. Samples from the deposit contained an average of 0.21 percent of $eThO_2$.

In the Kaiparowits Plateau area, 1 fossil placer is at the north end of the plateau 6 miles south of Escalante in Garfield County, and 13 are at the southern part of the Kaiparowits Plateau in Kane County.

TABLE 87.—*Mineralogical composition, in percent, of monazite-bearing concentrates from beach sands on the gulf coast of Texas*

[Modified from Bullard (1942, p. 1028, table 2)]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Apatite	1	1	----	----	----	2	1	1	----	----	----	----	1	1	----	----	----	----	1	1	----	1	----
Augite	12	17	9	5	8	5	4	7	6	1	1	1	2	2	----	1	----	----	1	1	2	1	2
Basaltic hornblende	6	8	10	4	9	10	9	12	8	----	1	1	1	1	----	----	----	----	1	2	1	1	1
Enstatite	1	----	----	1	1	----	----	1	1	----	----	1	----	----	----	----	----	----	1	1	2	1	1
Epidote	6	6	7	6	6	6	8	5	4	5	3	3	3	4	1	3	----	6	9	7	7	5	5
Garnet	5	3	7	6	5	2	5	3	1	1	----	2	5	7	9	8	7	12	8	5	6	4	7
Hornblende	8	15	8	6	16	21	15	27	24	9	7	15	24	24	4	8	----	9	22	22	16	15	17
Hypersthene	2	2	2	1	2	2	1	----	1	1	----	----	1	1	----	----	----	----	----	1	1	----	----
Kyanite	1	1	3	1	----	2	1	1	----	2	1	----	2	1	----	----	----	1	2	1	----	2	----
Leucoxene	4	8	8	4	7	12	5	9	13	9	12	16	24	19	4	10	3	12	10	11	14	15	13
Limonite	1	2	----	2	2	3	2	1	1	1	2	1	2	----	1	2	1	1	1	1	5	4	1
Monazite	3	2	3	3	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	1	3	1
Opaque black minerals	41	31	34	53	40	29	40	23	28	46	54	35	17	23	45	45	58	36	28	26	27	35	33
Rutile	1	----	1	----	----	----	1	1	----	1	1	2	3	1	1	----	1	1	3	----	2	1	----
Staurolite	2	1	1	2	1	1	1	1	3	3	4	3	5	1	1	1	1	2	3	3	1	2	2
Tourmaline	2	1	4	1	1	2	3	5	6	11	5	11	7	5	1	5	1	3	5	8	4	5	4
Zircon	4	2	3	5	1	2	3	2	3	9	8	8	2	9	32	16	26	15	3	7	11	5	6

1. Brazos Santiago, Cameron County.
2. South end of Padre Island, Cameron County.
3–4. Padre Island, Cameron County.
5–6. Padre Island, Willacy County.
7–9. Padre Island, Kenedy County.
10. Padre Island, Kleberg County.
11. North end of Padre Island, Nueces County.
12. South end of Mustang Island, Nueces County.
13. North end of Mustang Island, Nueces County.
14. St. Joseph Island, Aransas County.
15–16. Matagorda Peninsula, Matagorda County.
17. Coast south of mouth of Brazos River, Brazoria County.
18. South end of Galveston Island, Galveston County.
19. Galveston Island, Galveston County.
20. North end of Galveston Island, Galveston County.
21–22. Patton Peninsula, Chambers County.
23. Coast west of Sabine Pass, Jefferson County; includes 6 percent pyrite.

The placer south of Escalante has an exposed length of 600 feet, width of 200 feet, and thickness of as much as 12 feet. It occupies a channel in massive white sandstone in the Straight Cliffs Sandstone (Dow and Batty, 1961, p. 11). A seam of coal is exposed about 60 feet below the fossil placer. In its upper half the placer is dark purple, very hard, and contains 0.09 percent of $eThO_2$. The lower half of the placer is dark buff, stratified, and averages 0.15 percent of $eThO_2$.

The placers in the southern part of the Kaiparowits Plateau include three in Rees Canyon, eight in Croten Canyon, and two in Sunday Canyon, Kane County (Dow and Batty, 1961, p. 11–14). The Rees Canyon deposits are reddish-brown soft sandstone having 0.06–0.09 percent of $eThO_2$. In Croten Canyon the fossil placers are exposed on the walls as much as 300 feet above the floor of the canyon, and only one is accessible from the floor. Outcrop lengths of the deposits are 200–580 feet, widths are 200–250 feet, and thicknesses are 4–5 feet. The two placers in Sunday Canyon cap benches on the canyon wall and are inaccessible from the floor. They are about 4 feet thick, 200–300 feet long, and 200 feet wide. A composite of three samples from accessible deposits in Croten Canyon contained 0.08 percent of $eThO_2$.

Recent auriferous placers at Hite in Garfield County and the Jensen district of Uinta County were reported by Day and Richards (1906b, p. 1216–1217) to contain small quantities of monazite. Concentrates from these localities have from a trace to 25.4 pounds of monazite per short ton:

	Composition of concentrate (lb per short ton)		
	Hite	Jensen district	
Magnetite	800	848	1,532
Chromite		677	321
Ilmenite	32		
Garnet	24	300	78
Hematite	1,032		
Monazite	Trace	25.4	2
Zircon	72	120	43
Quartz	24	22	16
Unclassified minerals	16		
Total	2,000	1,992.4	1,992

The concentrates from the Jensen district were reported to have come from gravel that contained 3 pounds of black sand per cubic yard. The original source of the monazite in this area is not known. In the Hite area, however, the monazite was probably reworked from fossil placers of Late Cretaceous age, an inference that is supported by the abundance of hematite in the concentrate. Hematite is a cement in the fossil placers.

VERMONT

Monazite-bearing Bethlehem gneiss of the Bellows Falls pluton is exposed in Vermont in the bend of the Connecticut River immediately south of the town of Bellows Falls, Windham County (Kruger, 1946, map).

At Ascutney Mountain, Windsor County, a complex stock of hornblende-biotite-nordmarkite, alkalic granite, and monzonite is intruded along a contact between carbonaceous quartz-sericite phyllite on the east and muscovite-biotite-epidote gneiss on the west (Daly, 1903, p. 14–36). The phyllite is greatly crushed and crumpled near the stock and displays a contact metamorphic aureole about 500 feet wide. The aureole consists of hornfels containing cordierite, sillimanite, corundum, and intensely pleochroic metamorphic biotite that has abundant pleochroic halos. A very large variety of alkalic rocks are present in the main stock, a subsidiary mafic stock, and dikes. Only one variety of rock is monazite bearing. This is hornblene-biotite-nordmarkite, which is the earliest of the four chief phases of the main stock. Monazite is an abundant accessory mineral, although it constitutes less than 1 percent of the rock, at exposures in the Windsor quarry on the flank of Ascutney Mountain (Daly, 1903, p. 56; Jacobs, 1934, p. 9). The monazite was said by Daly to occur as nearly colorless gray grains having a yellow tint. All observed grains lack crystal form. They are rounded to subrounded and reach a maximum diameter of 0.04 inch. Very small needles of apatite and square sections of magnetite are present in the monazite. Primary allanite, intergrown in many places with hornblende, forms mantles about some of the grains of monazite.

The association of allanite with monazite in the earliest phase of the stock and the absence of monazite from later rocks suggests that a reaction between the monazite and the magma was taking place as the nordmarkite was emplaced. Continued reaction apparently led to elimination of monazite in later phases of the intrusive at Ascutney Mountain. Whether the absence of crystal form in the monazite grains was due to rounding resulting from reaction with the magma, or to low power of crystallization of the monazite is not known.

The alteration of monazite to allanite has been observed in some pegmatites in the United States and has been related to reactions associated with declining pressure and temperature. Possibly at Ascutney Mountain the monazite formed early in the magma chamber and as conditions of pressure and temperature dropped during the intrusion of the different phases of the stock, reactions took place between the monazite and the magma resulting in the disappearance of monazite as a mineral phase. Allanite and other minerals proxy for the monazite at lower pressure and temperature.

VIRGINIA

CRYSTALLINE ROCKS

The first published reports of monazite in Virginia were a group of analyses made by Dunnington and König in 1882 on massive monazite from a mica mine in pegmatite near Amelia Court House, Amelia County (Dunnington, 1882a, p. 154; 1882b; König, 1882a; 1882b). Thereafter, monazite from the Amelia area was mentioned in 21 of the 29 other reports which reported occurrences in the State, although the Amelia mica mines are of no importance as a commercial source for monazite.

The first systematic account of the distribution and occurrence of monazite in the State was prepared in 1953 by Mertie (1953, p. 15–16, pl. 1) as the result of his studies of the resistate heavy accessory minerals in the weathered rocks of the Southeastern States. Mertie observed that monazite occurs in some bodies of granite and granite gneiss exposed in a belt that extends southward from the vicinity of Five Mile in Spotsylvania County a few miles west of Fredericksburg to the James River in Goochland County at a point west of Richmond. At the James River the belt of monazite-bearing plutonic rocks was found by Mertie to split into two segments: an eastern segment that extends generally southward to the State line near Bracey (Sears, 1955) in Mecklenburg County and a western segment that extends southwestward from the James River to the State line near Stuart in Patrick County. As of 1953 Mertie described 27 localities where monazite-bearing rocks are present in these belts, and these occurrences have since been cited as the principal known localities in the State (Dietrich, 1958, p. 53).

In the area from Five Mile south to the James River, monazite was found by Mertie (1953, p. 16) to be present in six samples of granite gneiss and one of granite. These include two samples of granite gneiss from the vicinity of Five Mile and one from Post Oak in Spotsylvania County, a specimen of granite gneiss from the basin of the Little River and a sample of granite from the Chickahominy River area in Hanover County, and two samples of granite gneiss from exposures near the James River west of Richmond in Goochland County.

In the area between the James River and the State line at Bracey in Mecklenburg County, monazite was found by Mertie (1953, p. 16) in granite exposed 7.4 miles southeast of Amelia Court House, Amelia County, and in gneissic granite from localities near Wilson in Dinwiddie County, Blackstone in Nottoway County, and South Hill in Mecklenburg County. Granite in Chesterfield County is monazite bearing. An analysis of the total rare-earth and thorium oxide precipitate from monazite from the granite in Chesterfield County was published; the precipitate was said to have constituted 61.3 percent of the monazite (H. J. Rose, Jr., oral commun., 1960). Recalculation of the published analysis shows the following chemical composition:

[Analysts: Murata and Rose (in Murata and others, 1957, p. 148)]

	Percent
La_2O_3	12.5
CeO_2	25.9
Pr_6O_{11}	2.6
Nd_2O_3	9.1
Sm_2O_3	1.8
Gd_2O_3	.9
Y_2O_3	1.7
ThO_2	6.8
Total	61.3

Monazite was found by Mertie (1953, p. 15–16) at 16 localities between the James River and the State line near Stuart, Patrick County. It occurs in granite gneiss near Macon and south of Tobaccoville within 0.4 mile of the Appomattox River in Powhatan County, in gneiss in Cumberland County near the Appomattox River north of Farmville, and in granite and granite gneiss exposed at three localities west of Farmville, Prince Edward County. Monazite-bearing granite was found in the vicinity of Madisonville and Red House, Charlotte County, in granite gneiss exposed near Renan, Pittsylvania County, in granite gneiss and aplitic granite about 0.5 mile southwest of Mountain Valley, Henry County, and in three occurrences of granite and two of granite gneiss around Stuart, Patrick County. In this same zone, monazite was found in magnetite-rich layers of mica schist east of Chestnut Knob, Henry County, by Stow (1955b, p. 2).

Mica mines in pegmatite dikes in the area around Amelia Court House, Amelia County, have been the source of museum specimens of massive monazite, but the mineral is not present in commercial quantities although individual masses that weigh from 8 to 20 pounds have been found (Dunnington, 1882b; Hotchkiss, 1884–85, p. 169; Watson, 1909, p. 131; 1917, p. 475–477; Sterrett, 1913, p. 1048; Jones, W. H., 1949b, p. 582). The area in which the dikes occur is underlain by a sequence of gneissic and schistose rocks cut by granitoid and gabbroic rocks (Lemke and others, 1952, p. 105–108; Pegau, 1929, p. 542–545; 1932, p. 36, 54, 61; Hickman, 1950). According to Lemke and associates, quartz-biotite schist, biotite augen gneiss, thinly foliated biotite schist and gneiss, garnetiferous mica schist and gneiss, and hornblende schist and gneiss of poorly understood age and relations are the main varieties of metamorphic rocks in the Amelia area. Garnetiferous gneiss rich in pegmatite and containing abundant graphite and sparse sillimanite is exposed at several places, but for the most part the metamorphic rocks seem to be at the kyanite-staurolite subfaices. Fine- to medium-grained foliated locally porphyritic biotite-quartz monzonite is the most common granitic rock in the area. Diorite is present in the western and southwestern part of the district. Pods, thin conformable stringers, and irregular masses of pegmatite occur in the quartz monzonite and diorite, and dikes of pegmatite, as much as several hundred feet wide and half a mile long, occur in the schists and gneiss.

The mica pegmatites of the Amelia area are distinctly discordant and strike about eastward, nearly normal to the trend of the pegmatite-bearing zones in the schist (Lemke and others, 1952, p. 106–108). Contacts are remarkably straight and regular. Most of the dikes are distinctly zoned with cores of massive quartz. The pegmatite dikes consist mainly of plagioclase, quartz, and perthite, with lesser amounts of muscovite and biotite. Accessory minerals are commonly garnet, beryl, black tourmaline, and apatite; very scarcely they are cassiterite, tantalite, allanite, sulfides, monazite, and other minerals. The scarce constituents were said by Lemke and associates to have formed late through deuteric or hydrothermal alteration. Late alteration led to mineralogically complex pegmatites such as those exposed at the Rutherford (Fontaine, 1883, p. 331; Pegau, 1928) and Morefield (Glass, 1935, p. 744) mines. These complex pegmatite dikes are extensively albitized and contain muscovite, zinnwaldite, tantalite, columbite, microlite, beryl, phenacite, topaz, monazite, cassiterite, apatite, sericite, and sulfide minerals.

The complex Morefield and Rutherford pegmatite dikes were described by Lemke, Jahns, and Griffitts (1952, p. 130) as having formed in two stages. In the first stage each dike crystallized inward from its walls with early crystallization of plagioclase and the formation of a border zone, a medium- to coarse-grained granitoid wall zone, an intermediate zone rich in graphic granite, an intermediate zone rich in blocky perthite, and a discontinuous quartz core. In the second stage of the pegmatites, solutions penetrated the dikes causing widespread replacement of quartz, perthite, and probably wall-zone plagioclase by sodic albite. Muscovite, zinnwaldite, and many less common minerals, including monazite, were thought to have formed then, but the details are imperfectly known.

Monazite occurs in pegmatite exposed by the Champion and Rutherford mines north of Amelia Court House and the Morefield mine east-northeast of Amelia. The first reports of monazite in the Amelia area referred to material found in the Rutherford mine in 1882. The monazite was said by Fontaine (1883 p. 337) to occur usually as large masses, never as single or small crystalls, but small single crystals were subsequently observed (Lemke and others, 1952, p. 130). As reported by Fontaine the masses of monazite are aggregates of distorted crystals which often show well-formed faces on individual particles. The masses are yellowish brown and dark grayish brown; a few are orange. Included in the dark-garyish-brown monazite are flakes of white mica. Commonly the different colors are associated in the same specimen. Where weathered, the monazite is gray and has an earthy luster. The later reports of Glass (1934, p. 754, 763) and Lemke, Jahns, and Griffiths (1952, p. 130) described reddish-amber to olive-brown monazite and stated that it occurs sparsely in albite as individual tabular skeletal crystals enclosing crystals of manganotantalite. It was said to closely resemble microlite.

Early analyses of monazite from the pegmatites at Amelia Court House are given in table 88. Dunnington's analysis showed 18.6 percent of ThO_2, and the analyses by Penfield disclosed 14.07 and 14.39 percent

TABLE 88.—*Chemical analyses of monazite, in percent, from pegmatites at Amelia Court House, Va.*

[Analysts: Dunnington (1882a), König (1882b), Penfield (1882 p. 252), and R. J. Strutt (in Hess, 1913, p. 1009) and H. J. H. Fenton in 1905. Symbol used: --, not determined]

		2	3	4	5
Ce_2O_3	16.3		29.89	--	--
La_2O_3	10.3		26.66	--	--
Di_2O_3	24.4			--	--
Y_2O_3	1.1	73.82	--	--	--
Er_2O_3 (group)	--		--	--	--
ThO_2	18.6		14.23	14.39	2.43
U_3O_8	--		--	--	.1
P_2O_5	24.04	26.05	26.12	--	--
SiO_2	2.7	--	2.85	--	--
Al_2O_3	.04	--	--	--	--
Fe_2O_3	.9	1.00	--	--	--
CaO	--		--	--	--
MgO	--	--	--	--	--
Loss on ignition	--	.45	.67	--	--
Total	98.38	101.32	100.42	--	--
Specific gravity	--	5.1–5.4	5.30	--	--

of ThO_2, but the analysis by Strutt indicated only 2.4 percent of ThO_2. The early analyses indicating high thorium oxide have subsequently been widely quoted (Watson, 1907, p. 303; 1916, p. 940; Glass, 1934, p. 234–235), but later analyses have disclosed somewhat less thorium oxide. Microchemical analyses of the monazite by Edith Kroupa showed the following amounts (Lane, 1934, p. 28):

	Percent	
	A	B
RE_2O_3	48.98	-------
ThO_2	7.21	7.89
U_3O_8	.2	-------
SiO_2	2.88	-------
Al_2O_3	3.43	-------
Fe_2O_3	1.90	-------
CaO	.87	-------
MgO	.23	-------
PbO	1.33	.93

The results of a spectrochemical analysis of the total rare-earth and thorium oxide precipitate from monazite from pegmatite at Amelia Court House has been published (Murata and others, 1953, p. 294). According to H. J. Rose, Jr. (oral commun., 1960) the precipitate was 71.02 percent of the monazite, and the published analysis when recalculated to sum 71.02 percent shows that the monazite from Amelia contains the following percentages:

	Percent
La_2O_3	11.40
CeO_2	26.44
Pr_6O_{11}	3.15
Nd_2O_3	12.90
Sm_2O_3	3.51
Gd_2O_3	1.15
Y_2O_3	1.36
ThO_2	11.11
Total	71.02

The Amelia Court House monazite contains from 11 to 14 percent of ThO_2, and this composition makes it among the most thorium oxide-rich monazite reported from the United States. Yet, it comes from an environment that is by no means the most plutonic in which pegmatites are found in the country. Also, monazite is relatively uncommon in the muscovite-bearing pegmatites of the Piedmont. The regional geologic relations and significance of the high-thorium oxide monazite in the mica pegmatites of the Amelia district is not as yet understood, but it is intriguing that the occurrence is virtually at the contact of the two belts of monazite-bearing rocks defined by Mertie (1953, pl. 1).

Monazite was said to occur in Lovingston Quartz Monzonite Gneiss exposed near the airport at Charlottesville, Albemarle County, and at a point about 8 miles west of Culpeper, Culpeper County (Stow, 1955b, p. 2). Outcrops of granodiorite gneiss 1.6 miles to the west of Sperryville contain accessory monazite which is unusually radioactive (Jaffe and others, 1959, p. 114).

FOSSIL PLACERS

Fossil placers of Precambrian(?) and Cambrian age have been observed in Virginia, but there is scant information about them. Quartzite of Precambrian(?) age associated with the Lovingston Quartz Monzonite Gneiss in Culpeper County was described by Mertie (1956, p. 1755) as being monazite bearing, and a detrital origin for the monazite was implied. A magnetite-rich layer 12–20 inches thick in Wissahickon Schist exposed 5.4 miles south-southwest of Martinsville, Henry County, was observed by Mertie (1955, p. 1692–1693) to consist of 69 percent of magnetite, 15 percent of ilmenite, 9 percent of monazite, 3 percent of zircon, 2 percent of corundum, and 2 percent of quartz and other minerals. The enclosing rocks are biotite-kyanite schist formed by the metamorphism of sedimentary rocks. The layer of heavy minerals was interpreted by Mertie to be a fossil placer. Detrital monazite was reported to be concentrated in sandstone of Early Cambrian age at several placers in the Blue Ridge in Virginia, but descriptions and locations of these fossil placers have not been published (Sears, 1955).

STREAM AND BEACH DEPOSITS

Monazite was found in 4 out of 19 concentrates panned from sand and gravel in tributaries to the Ararat River and Dan River in the southwestern part of Patrick County (A. M. White, written commun., 1954). A sample of fluvial gravel from a tributary to the Ararat River contained 0.2 pound of monazite per cubic yard. Three tributaries to the Dan River were the sources of gravel with small amounts of monazite:

	Tenor of gravel (lb of monazite per cu yd)
Big Creek	0.2
Archies Creek	.06
Squirrel Creek	.3

The concentrates consisted mainly of magnetite, epidote, staurolite, small quantities of ilmenite, and a trace of garnet and zircon. The deposits are not commercial sources of monazite.

A few grains of monazite were found in concentrates panned from gravel in Birch Creek, Pittsylvania County, and Sandy Creek, Halifax County (J. W. Whitlow, oral commun., 1953).

A petrographic study of Recent beach sand along the coast of Princess Anne County from Cape Henry southward to the State line was made by Alford, Kane, and Marthison (1956). Results of the study showed that the sands throughout this distance contain the same minerals but with a systematic southward variation in character of the grains. A southward decrease in the abundance of magnetite, ilmenite, and less stable minerals was noted. Also seen was a southward decrease in the average grain size and an increase in the degree of roundness of the grains. In the order of decreasing frequency of occurrence of the grains in the beach sands, the heavy suites consist of magnetite, ilmenite, leucoxene, zircon, garnet, epidote, staurolite, hornblende, kyanite, tourmaline, sillimanite, muscovite, monazite, hypersthene, brookite, topaz, diopside, olivine, biotite, and enstatite. The geologic source of the heavy minerals was not determined, but their main geographic source was thought by Alford, Kane, and Marthison to be the Chesapeake Bay, the sediments of which had previously been shown (Jaffe and Hughes, 1953) to be very slightly radioactive. Evidently monazite is much too scarce along the coast of Princess Anne County to form workable monazite placers.

WASHINGTON

Monazite was listed by Glover (1936, p. 8–9) in a tabulation of 52 nonmetallic minerals of no economic importance which occur in various rocks and veins exposed in Washington, but localities and modes of occurrence were not given. The apparent sparseness of monazite in the State was further indicated by its absence from the bibliography and indexes of mineral occurrences compiled by Bennett (1939, p. 91–124). There are, however, a few reports that describe minor occurrences of monazite in crystalline rocks, lake sediments, stream deposits, and the beaches of Washington.

Monazite occurs in biotite-rich pegmatitic segregations near the contacts of granite with gneiss and schist in the vicinity of Sherman Creek Pass, Columbia Mountain, and Sherman Park in Ferry County. These deposits were explored by pits and diamond-drill holes in the early 1950's when hundreds of claims were staked in the area, but as of 1956 the deposits had not been exploited (Huntting, 1956, p. 352).

Residual and colluvial clay deposits derived from granitic and metamorphic rocks near Freeman, Spokane County, were reported by Goodspeed and Weymouth (1928) to contain accessory monazite. A clay pit near Freeman was found by J. W. Hosterman (oral commun., 1963) of the U.S. Geological Survey to expose weathered monazite-bearing granodiorite. He also found weathered monazite-bearing garnetiferous sillimanite schist a short distance west of Saltese Flats, Spokane County.

Analyses of two samples of monazite separated by Hosterman from concentrates panned from residuum and of a sample from sedimentary rock exposed in Spokane County are given in table 89. The results of these analyses show that monazite in this part of Spokane County contains about 3.6 percent of ThO_2. The amount of monazite in the granodiorite and sillimanite schist seems to be too low for monazite mining, and even if the monazite were concentrated in placers, the tenor in thorium oxide is too low for commercial exploitation unless special economic factors were to intervene.

TABLE 89.—*Thorium and uranium composition, in percent, of monazite from Spokane County, Wash.*

[Analyst: J. J. Warr, Jr., U.S. Geol. Survey, in 1963]

Lab. No.	Source of monazite	Location	ThO_2	U_3O_8
160816	Saprolite of granodiorite	Clay pit at Freeman, sec. 1, T. 23 N., R. 44 E.	2.74	0.65
17	Saprolite of garnetiferous sillimanite schist.	Drill hole on point of hill 0.95 mile west of Saltese Flats, sec. 32, T. 25 N., R. 44 E.	4.06	.20
18	Sedimentary rock, Latah Formation.	Sommers clay pit, sec. 35, T. 25 N., R. 44 E.	3.92	.26

At a locality 4 miles northwest of Okanogan on Happy Hill, Okanogan County, 15 claims and some leased land were prospected in the early 1950's, and ore containing as much as 5 percent of monazite was found (Huntting, 1956, p. 353). Geology of the occurrence was not discussed by Huntting.

Kaolin deposits of lacustrine origin in the Freeman, Mica, and Chester areas of Spokane County were said by Goodspeed and Weymouth (1928, p. 687) to be associated with sandy layers containing minor detrital monazite.

Sedimentary rocks in the Latah Formation of Tertiary age exposed at the Sommers clay pit near Spokane in Spokane County contain detrital monazite (J. W. Hosterman, oral commun., 1963). Because the detrital monazite is nearly identical to monazite from sillimanite schist west of the Saltese Flats in amount of thorium oxide and uranium oxide, it seems likely that the detrital monazite was locally derived from metamorphic rocks. Possibly the most favorable places in the area for fluviatile or lacustrine monazite placers would be where sedimentary rocks of the Latah Formation serve as an intermediate host for monazite.

Stream sediments in at least six places in the State are known to contain detrital monazite, but the mineral is of no economic importance at any of these localities. Stream gravel at Marcus in Stevens County, the Wilmont Bar gold placer on the Columbia River in Ferry County, the Columbia River in Douglas County, the Snake River in Asotin County, and the Seattle gold placer in King County is monazite bearing (Day and Richards, 1906b, p. 1216–1219; Huntting, 1956, p. 184). Terraces 20 and 100 feet above the Columbia River at the Wilmont Bar placer contain monazite, magnetite, ilmenite, and zircon (Huntting, 1956, p. 184). For the most part the fluvial sediments were reported to have only a trace of monazite, but concentrates from the Wilmont Bar contain 30 pounds of monazite per short ton (table 90). At Brush Prairie, Clark County, an auriferous concentrate probably of placer origin was said by Day and Richards (1906b, p. 1218–1219) to contain a trace of monazite. Gold placers at Sherman Creek Pass, Ferry County, are monazite bearing.

Beach deposits in Clallam County, at Moclips in Grays Harbor County, and in Pacific County are sparsely monazite bearing. One sample of natural beach sand from Moclips was said by Day and Richards (1906b, p. 1218) to contain 71.5 pounds of monazite per short ton of sand as found on the beach. No commercial sources for monazite have been found in these placers, and they are not likely to be present.

WEST VIRGINIA

Paleozoic sandstones in West Virginia were noted by Martens (1932, p. 72–73) to contain minor amounts of detrital monazite along with more common detrital heavy minerals like zircon, rutile, ilmenite, magnetite, and mica. The monazite was found in sandstones ranging in age from Late Devonian to Pennsylvanian in about 60 samples from 12 oil and gas wells in the northern part of the State in Wetzel, Monongalia, Tyler, and Marion Counties. It occurs as small well-worn light-yellow grains. One or two grains of monazite were found in most of the heavy fractions in which it was seen. From this sparseness Martens (1939, p. 15) inferred that the monazite might also have been present in other sandstones where it was absent from the small concentrate that was studied. In any event the monazite seems only to be a mineralogical curiosity in these rocks. Martens observed sparse monazite in all six concentrates collected from sandstone in the Chemung Formation of Devonian age near Rowlesburg, Preston County (Martens, 1939, p. 24). Other heavy minerals were leucoxene, muscovite, chlorite, biotite, zircon, tourmaline, rutile, pyrite, apatite, anatase, brookite, xenotime, and ilmenite. Oriskany Sandstone of Devonian age in Kanawha County was found to have less than 0.01 percent total heavy minerals, exclusive of pyrite, of which monazite was a very minor component. Nine stratigraphic units intersected by the J. L. Jamison well 1, 2 miles southwest of Morgantown, Monongalia County, contained very scarce monazite among the accessory minerals (table 91). Monazite may account for some of the radioactivity noted by McKeown (1954, p. 166) in exposures of the Mississippian Pocono Formation 1.3 miles south of Marlinton, Pocahontas County.

WYOMING

Although allanite and other rare-earth and thorium-bearing minerals have been reported by several writers to occur in iron-manganese veins, pegmatite, granite, altered monzonite and syenite porphyry, and gneiss in Wyoming, there seems to be no reported occurrence of monazite in crystalline rocks of the State (Osterwald and Osterwald, 1952, p. 166). The main known deposits of monazite are fossil placers in sandstone in the Deadwood Formation of Cambrian age and sandstones of Cretaceous age. The very few

TABLE 90.—*Mineralogical composition, in pounds per short ton, of monazite-bearing auriferous sands and concentrates from streams and beaches in Washington*

[Modified from analyses by Day and Richards (1906, p. 1216–1219). Symbol used: --, absent]

	1	2	3	4	5	6	7	8	9	10
Magnetite	1,096	1,308	1,414	936	900	1,176	40	72	8	822
Chromite	--	--	150	--	--	--	--	24	4	--
Ilmenite	56	150	188	512	150	328	1,120	82	53	240
Garnet	432	272	--	--	600	320	424	--	--	20
Olivine	--	--	--	--	--	--	--	1,597	118	--
Monazite	Trace	30	6	Trace	Trace	Trace	Trace	71.5	Trace	Trace
Zircon	--	60	24	16	50	Trace	96	10	--	Trace
Quartz	344	50	84	--	--	--	--	12	1,330	396
Other minerals	72	30	132	536	300	176	[1] 120	[1] 122	487	[1] 520

[1] Platinum bearing.

1–4. Concentrate from gravel.
1. Marcus, Stevens County.
2. Wilmont Bar, Columbia River, Ferry County.
3. Columbia River, Douglas County.
4. Snake River, Asotin County.

5. Concentrate from sand.
5. Snake River, Asotin County.

6–7. Undescribed source.
6. Brush Prairie, Clark County.
7. Clallam County.

8–10. Natural beach sand.
8. Moclips, Grays Harbor County.
9. Grays Harbor County.
10. Pacific County.

TABLE 91.—*Mineralogical composition of heavy fraction of sandstone of Paleozoic age in the J. L. Jamison well 1, Monongalia County, W. Va.*

[Modified from Martens (1939). Symbols used: VA, very abundant; A, abundant; C, common; S, scarce; VS, very scarce; Ab, absent]

Formation or member	Depth (feet)	Number of samples	Pyrite	Muscovite	Biotite	Chlorite	Zircon	Rutile	Leucoxene	Brown tourmaline	Green tourmaline	Blue tourmaline	Garnet	Ilmenite	Anatase	Monazite	Xenotime
Buffalo and Mahoning	165–205	7	S	A	S	C	C	VS	C	S	VS	VS	S	Ab	S	S	Ab
Allegheny	255–485	18	VA	C	VS	S	C	VS	C	S	VS	VS	VS	Ab	VS	VS	Ab
Pottsville	523–732	33	A	C	VS	S	A	VS	A	S	VS	VS	VS	Ab	VS	VS	VS
Mauch Chunk	732–964	16	C	C	VS	S	C	VS	A	C	VS	VS	VS	Ab	VS	VS	VS
Greenbrier	1,101–1,182	18	C	VS	Ab	Ab	A	S	A	C	S	S	VS	C	VS	VS	VS
Big Injun	1,197–1,250	11	C	S	Ab	VS	C	VS	A	C	S	S	Ab	VS	S	VS	VS
Pocono below Big Injun	1,250–1,762	45	A	S	Ab	VS	C	S	A	C	S	S	Ab	Ab	VS	VS	VS
Catskill	1,783–2,218	43	A	S	VS	VS	C	VS	A	C	S	S	VS	Ab	VS	VS	VS
Chemung	2,246–3,077	62	A	C	S	S	C	S	C	C	S	S	VS	Ab	VS	VS	VS

concentrations of monazite in Recent stream sediments that have been reported are spatially associated with the fossil placers.

FOSSIL PLACERS OF CAMBRIAN AGE

Occurrences of monazite in sluice concentrates and natural sand of the Bald Mountain district in the Big Horn Mountains, Sheridan and Big Horn Counties, Wyoming, were mentioned by Day and Richards (1906b, p. 1220–1221), and the report was repeated in 1917 by Schrader, Stone, and Sanford (1917, p. 346), but the source of the monazite was apparently unknown. Even the quantities of monazite observed in the sluice box concentrates and sand were a poor indication of the size and tenor of the source. The amount of monazite per short ton of concentrate or sand was found by Day and Richards and is indicated in the following table:

	Pounds per short ton	
	Sluice-box concentrate	*Natural sand*
Magnetite	1,931	5
Chromite	None	1.2
Ilmenite	29	None
Garnet	None	17
Olivine	None	1
Monazite	2	2
Zircon	37	3.6
Quartz	.8	1,592
Other minerals	None	376
Gold	Present	Present
Total	1,999.8	1,997.8

The source of the monazite from Bald Mountain was found to be a bed of quartz-pebble conglomerate at the base of the Deadwood Formation of Cambrian age where that formation rests on granite (McKinney and Horst, 1953, p. 7). Hematite and limonite in the matrix give the conglomerate a red cast. Associated with the monazite in the quartzite are detrital ilmenite, magnetite, garnet, and zircon. About half of the monazite grains in the conglomerate of the Deadwood Formation are smaller than 100-mesh (Borrowman and Rosenbaum, 1962, p. 3):

Screen size (mesh)	*Percent*
−10+100	52
−100+200	17
−200	31
Total	100

Monazite from the Deadwood fossil placer is unusually rich in thorium oxide. Seven analyses by the U.S. Bureau of Mines showed an average of 8.8 percent of ThO_2 and 0.12 percent of U_3O_8 (McKinney and Horst, 1953, p. 25; Kauffman and Baber, 1956, p. 6; Borrowman and Rosenbaum, 1962, p. 2): The composition was as follows: ThO_2, 8.68, 8.8, 8.8, 8.8, 8.9, 8.6, 9.2; U_3O_8, 0.10, 0.13, 0.12, 0.11, 0.11, 0.14, and 0.14.

A drilling program by the U.S. Bureau of Mines in 1952 disclosed that the conglomerate at the base of the Deadwood Formation in the vicinity of Bald Mountain is 20–50 feet thick and contains 20 million short tons of rock averaging 2.5 pounds of monazite per short ton. Included in this average is a high-grade layer 2.5–10 feet thick immediately above the contact and estimated to contain 675,000 short tons of conglomerate having 13.2 pounds of monazite per short ton (Borrowman and Rosenbaum, 1962, p. 2).

FOSSIL PLACERS OF LATE CRETACEOUS AGE

Monazite-bearing titaniferous fossil placers of Late Cretaceous age have been observed in at least 13 places along the margins of intermontane basins in Wyoming (Murphy and Houston, 1955, p. 190–193; Chenoweth, 1957, p. 212; Dow and Batty, 1961, p. 16–34). These deposits are similar in origin to the Upper Cretaceous titaniferous sandstones in the San Juan Basin of New Mexico and Colorado; however, the Wyoming deposits contain less monazite than the placers in the States to the south. Most of the fossil placers were formed as beach concentrates and represent the transition from marine to nonmarine beds (Murphy and Houston, 1955, p. 190). The zones of concentration of heavy minerals consist of common ilmenite, anatase, and rutile accompanied by magnetite, zircon, garnet, monazite, tourmaline, epidote, staurolite, spinel, ilmenorutile, and sphene with a cement of hematite and calcite. These zones of concentrated heavy minerals tend to be elongate, narrow, and thin like present-day beach deposits, and they were said by Murphy and Houston generally to occur with clean well-sorted massive sand stone beds of the littoral type. They do not extend for long distances; the longest deposits known reach a length of about 4 miles, and layers of black sand may be deposited at several stratigraphic horizons in one locality.

Reports by Murphy and Houston (1955, p. 190–193) and Dow and Batty (1961, p. 16–34) showed that there were at least 19 placers at 13 localities in Wyoming. These 19 deposits were estimated by Dow and Batty (1961, p. 6) to contain 22 million short tons of titaniferous sandstone having an average tenor of 5.22 percent of TiO_2, 0.55 percent of ZrO_2, and 0.015 percent of $eThO_2$. Similar deposits in New Mexico and Utah contain about a nine times greater percentage of $eThO_2$. The main fossil placer areas in Wyoming are the Bighorn Basin, Wind River Basin, and Rock Springs Uplift. Individual deposits are known in the Laramie Basin, Uinta Mountains, and near Cumberland Gap. Murphy and Houston stated that the fossil placers in the Bighorn Basin are in the basal part of the Mesaverde Formation, those in the Wind River Basin in sandstone in the Lewis Shale or its equivalent, and those in the Rock Springs Uplift in the lower part of the Ericson Sandstone. Poor exposure of the placer in the Laramie Basin makes identification of the host rock doubtful, but it was thought by Murphy and Houston to be the Pine Ridge Sandstone Member of the Mesaverde Formation. The fossil placer in the Uinta Mountains is in the Ericson Sandstone (Dow and Batty, 1961, p. 18), and the deposit at Cumberland Gap is in the lower part of the Frontier Formation (Murphy and Houston, 1955, p. 190).

Fossil placers in the Bighorn Basin are known as the Grass Creek North, Grass Creek South, Waugh, Mud Creek, Dugout Creek, Lovell, and Cowley deposits (Dow and Batty, 1961, fig. 1).

The Grass Creek North deposit caps a cliff of Mesaverde Sandstone about 1.5 miles northeast of Riverton, Hot Springs County, on the north limb of the Grass Creek anticline, and the smaller Grass Creek South deposit occurs on the south limb of the anticline about 3 miles southeast of the community of Grass Creek in Hot Springs County (Dow and Batty, 1961, p. 30–32). The two deposits seem to be erosional remnants of a single placer. Titaniferous sandstone at the northern deposit has an exposed length of 3,700 feet, width of 300 feet, and an average thickness of 8 feet. A composite of nine samples from the placer was reported by Dow and Batty to contain an average of 21.5 percent of TiO_2, 3.0 percent of ZrO_2, and 0.09 percent of $eThO_2$. At the southern deposit the titaniferous sandstone is exposed for a length of 1,300 feet with an average thickness of 4 feet. Three samples from the outcrop averaged 15.6 percent of TiO_2, 1.6 percent of ZrO_2, and 0.09 percent of $eThO_2$. According to Murphy and Houston (1955, p. 192), the heavy minerals at the Grass Creek fossil placer area, separated from matrix and magnetite, are as follows:

	Percent
Ilmenite and anatase	78
Zircon	17
Garnet	3
Rutile	1
Monazite	.5
Tourmaline	.3
Total	99.8

The nearby Waugh fossil placer was described by Dow and Batty (1961, p. 33) to be in Hot Springs County 16 miles southeast of the town of Grass Creek. The placer is 200 feet long, 150 feet wide, 4 feet in average thickness, and, as shown by one sample, contains 11.1 percent of TiO_2, 1.5 percent of ZrO_2, and 0.04 percent of $eThO_2$.

The Mud Creek fossil placer in Washakie County is 26 miles southeast of Worland (Dow and Batty, 1961, p. 28–30). It was apparently formed by stream action instead of marine processes, because it occupies a channel in sandtstone of the Mesaverde Formation. Erosion by Mud Creek has divided the fossil placer into two parts which are exposed for 175 and 350 feet along the sides of the stream. The average thickness of the deposits is 6 feet and the maximum width is 200 feet. A composite of three samples of titaniferous sandstone from the Mud Creek placer contained 8.0 percent of TiO_2, 0.5 percent of ZrO_2, and 0.02 percent of $eThO_2$.

The largest fossil placer known in the Upper Cretaceous rocks of Wyoming was reported by Dow and Batty (1961, p. 26–30) to be a channel deposit in sandstone of the Mesaverde Formation exposed at Dugout Creek in Washakie County. Like the deposit on Mud Creek, the placer on Dugout Creek is also divided into two segments by stream erosion. The northern segment is exposed for a length of 5,300 feet and a width of 1,000 feet with an average thickness of 20 feet. Extensions toward the north and west are covered by younger rocks. The southern segment has an exposed length of 6,400 feet, width of 1,900 feet, and an average thickness of 18 feet. It is possibly much larger. Analyses of samples from the outcrops of the two segments of the fossil placer disclosed the very low average of 0.01 percent of $eThO_2$. The percentages of TiO_2 and ZrO_2 were respectively 4.2 and 0.4.

A fossil placer crops out on a mesa 6 miles southeast of Lovell in Big Horn County (Dow and Batty, 1961, p. 26). It consists of a layer of titaniferous sandstone 3,700 feet long, 400–600 feet wide, and 2–12 feet thick. The single sample of titaniferous sandstone from this area that has been analyzed proved to be nonradioactive. Northwest of the Lovell deposit, a large low-grade mass of titaniferous sandstone is exposed on a mesa 1.5 miles southwest of Cowley, Big Horn County. It is 2,500 feet long, as much as 600 feet wide, and 2–6 feet thick. An analysis of one sample from the Cowley deposit disclosed 2.7 percent of TiO_2, 0.2 percent of ZrO_2, and 0.01 percent of $eThO_2$ (Dow and Batty, 1961, p. 26).

Fossil placers near the east margin of the Wind River Basin are known at Clarkson Hill, Poison Spider, and Coalbank Hills, Natrona County (Dow and Batty, 1961, p. 22–26). The body of titaniferous sandstone at Clarkson Hill crops out about 27 miles west of Casper. It has an exposed length of 300 feet and an average thickness of 4 feet. Inasmuch as the exposure probably discloses the width of the deposit, its length may be much greater than 300 feet and its volume correspondingly large. Analyses of two samples of the titaniferous sandstone showed an average of 9.7 percent of TiO_2, 1.3 percent of ZrO_2, and 0.04 percent of $eThO_2$. The Poison Spider fossil placer locality is 30 miles west of Casper. The placer, in a sandstone member of the Lewis Shale, is exposed for a length of 300 feet and has a thickness of 4 feet. Percentages of TiO_2, ZrO_2, and $eThO_2$ averaged from three samples are respectively 7.3, 0.7, and 0.03. The Coalbank Hills fossil placer is 17 miles southwest of Waltman. The placer has been eroded into two segments which extend for 2,500 feet along the strike of the enclosing sandstone. Monazite seems to make up only a very small percentage of the heavy minerals, because a composite of five samples contained only 0.004 percent of $eThO_2$.

Six fossil placers known collectively as the Salt Wells Creek deposits are exposed to the south-southeast of Rock Springs in the Rock Springs Uplift of Sweetwater County (Dow and Batty, 1961, p. 16–22). The deposits occur in the basal part of the Ericson Sandstone. They range in size from a body about 200 feet long and 3 feet thick of undetermined width to a layer of titaniferous sandstone about 2,500 feet long, 150 feet wide, and 7 feet thick. Monazite has been observed as a minor constituent of the heavy suite, and analyses of the sandstone show from 0.04 to 0.1 percent of $eThO_2$.

In the Laramie Basin at the north end of Sheep Mountain 25 miles west of Laramie, Albany County, a fossil placer consisting of titaniferous sandstone is exposed for a distance of 525 feet (Dow and Batty, 1961, p. 22). The placer is considerably fractured. It is at least 15 thick and 60 feet wide. Monazite is a minor component of the placer, and an analysis of a composite of five samples revealed only 0.04 percent of $eThO_2$.

On the north flank of the Uinta Mountains 40 miles south of Rock Springs, the Red Creek fossil placer is exposed on the east side of Red Creek, Sweetwater County (Dow and Batty, 1961, p. 16). Titaniferous sandstone at the Red Creek deposit crops out for a length of 800 feet and a width of 100–200 feet through a maximum thickness of 8 feet. Monazite is a minor component of the sandstone, and the analysis of a composite of five samples of the sandstone showed only 0.04 percent of $eThO_2$.

Titaniferous deposits near Cumberland Gap, Uinta County, about 17 miles south of Kemmerer, are intermittently exposed for 22,000 feet in ridge-forming sandstone in the lower part of the Frontier Formation (Dow and Batty, 1961, p. 33–34). Although one of the deposits is 13 feet thick, the average thickness is only 5 feet. The fossil placers dip under younger formations; therefore, their size cannot be determined from surface exposures. Monazite in small amounts accompanies the other heavy minerals, but the heavy-mineral-bearing zones are difficult to distinguish from the rest of the sandstone because the entire sandstone is dark brown to buff. Samples from the outcrop contain less than 0.01 percent of $eThO_2$.

RECENT ALLUVIAL DEPOSITS

In addition to the occurrence of monazite in Recent alluvial deposits in the vicinity of the fossil placers of Cambrian age in the Bald Mountain district, previously mentioned, the mineral has also been reported from a locality along the Green River, Sweetwater County, where Day and Richards (1906b, p. 1220–1221) found a trace of monazite in a short ton of natural sand.

SOUTH AMERICA

The many placers in marine beaches and elevated bars along the south coast of Brazil were the world's main source of commercial monazite from 1895 through 1913. They still constitute one of the larger known sources, but new discoveries in North America, Africa, and Asia considerably lessen their international importance. Placers along the coast of Uruguay resemble the Brazilian deposits. Fluviatile and primary deposits of monazite in the interior of Brazil constitute an immense resource.

ARGENTINA

The descriptive lists of Argentine minerals compiled by Ahlfeld and Angelelli (1948), Angelelli (1950), and Amato (1956, p. 51–69) did not include references to monazite, but as early as 1889 this mineral had been reported among the accessory heavy minerals in decomposed granite and gneiss at Córdoba, Córdoba Province (Derby, 1889, p. 113). In 1962 a discovery of over 30 million tons of sand said to contain 7 percent of heavy minerals, including a small amount of monazite, was reported in Córdoba Province, but the nature of the occurrence was not described (Eng. and Mining Jour., 1962).

According to Angelelli (1956, p. 63, 67), masses of monazite have been found in pegmatite dikes which intrude gneiss of Precambrian age at the Sierra de Valle Fértil, San Juan Province. The sizes of the masses and the amount of monazite in the dikes were not described.

Detrital monazite associated with zircon was observed in sand along the banks of the Río de la Plata at Buenos Aires on the Argentine side and at Punta Caballos on the Uruguayan shore (Derby, 1889, p. 113; Johnstone, 1914, p. 58). Alluvial gold and tin placers at Orosmayo, Río Cincel, Río del Candado (Río Candado), and elsewhere in the interior of Argentina were stated to contain monazite (Angelelli, 1956, p. 65–67). Sand in Riocito (Riecito Stream) at La Carolina in San Luis Province contains monazite (Mining World, 1952). Monazite probably occurs locally along the Atlantic beaches of Argentina.

An output of 1 ton of monazite in 1956 was reported for Argentina (J. G. Parker, written commun. 1962).

BOLIVIA

Crystals of monazite weighing as much as 7 pounds have been found in columbite-bearing muscovite pegmatite exposed 3 miles north of Mina Verde near San Agustín, Santa Cruz, Bolivia (Hinckley, 1945, p. 16; Ahlfeld, 1954, p. 229; Ahlfeld and Muñoz Reyes, 1955, p. 135). The area is underlain by granite, gneiss, and schist; many pegmatite dikes are in the granite. The pegmatite dikes are composed mainly of feldspar, usually weathered to kaolin, and quartz. They commonly have quartz cores. Monazite-bearing pegmatite dikes have columbite in the core and muscovite in the wall zone, but the position of the monazite was not indicated. The monazite is a minor accessory mineral and is less abundant than the columbite. An analysis of the monazite showed that it contained the amount of thorium oxide shown:

[Analyst: R. Herzenberg (in Ahlfeld, 1954, p. 229)]

	Percent
$(Ce, La)_2O_3$	52.2
ThO_2	10.1

Near Sorata, a molybdenite-bearing pegmatite dike in granite intrusive into quartzite questionably contains monazite (Ahlfeld and Muñoz Reyes, 1939, p. 106). Monazite was dubiously reported (Ahlfeld and Muñoz Reyes, 1955, p. 135) in tin deposits at Chorolque, La Unión, and Huayna Potosí.

Monazite was reported by Beard (1930, p. 109) and Ahlfeld (1931, p. 249) to be a rare accessory mineral and by Gordon (1944, p. 286–301) to be a common but minor accessory mineral in the cassiterite veins at Cerro de Llallagua. At Llallagua an elliptically shaped body of quartz porphyry intrudes graywacke and shale of Devonian age. The porphyry and the sedimentary rocks for a distance of 1,000 feet from the porphyry are extensively altered to muscovite, tourmaline, and quartz. After the porphyry and graywacke were hydrothermally altered, fissures formed normal to the long axis of the body of porphyry, and pneumatolytic solutions deposited the vein-forming minerals. Most of the veins are in the porphyry, but a few are in the graywacke and shale. The veins are vuggy, and the vein minerals seem to have been deposited in open fissures. The sequence of mineralization is interpreted by Gordon (1944, p. 300–301) to have begun with the growth of quartz crystals on the walls of the fissures. The quartz was followed by bismuthinite, cassiterite, wolframite, apatite, monazite, and pyrrhotite. As the temperature of the solutions decreased, the pyrrhotite was replaced by marcasite, franckeite, wurtzite, galena, pyrite, siderite, sphalerite, and stannite. Apatite is the main gangue mineral in many veins. The monazite is flesh pink, and occurs as translucent prisms, twinned crystals, and coarse granular aggregates intergrown with cassiterite and as small twin crystals overgrown on prismatic quartz in vugs. A chemical analysis showed that the monazite is devoid of thorium:

[Analyst: Gordon in 1939 (in Gordon, 1944, p. 330)].

	Percent
Ce_2O_3 (group)	31.41
La_2O_3 (group)	33.19
Y_2O_3	5.08
ThO_2	.00
P_2O_5	29.29
SiO_2	.27
CaO	.34
MgO	.22
Total	99.80

The specific gravity of this monazite was determined as 5.173 by Parrish (1939, p. 652). The absence of thorium was confirmed by spectrographic analysis and examination with a Geiger-Müller counter (Gordon, 1944, p. 330).

No monazite has been produced in Bolivia.

BRAZIL

The first notice of monazite in Brazil appeared in a report by Gorceix (1883, p. 32). He found yellow grains, which he tentatively identified as monazite, in sand reputed to have come from streams around the Fazenda Quebra-Cangalha in São Paulo, but which he later said originated near Caravelas, Bahia (Gorceix, 1884a, p. 182). During 1884 and 1885 Gorceix confirmed the identity of the mineral as monazite, and he extended its known distribution in Brazil to the State of Minas Gerais where he found it in diamond placers at Diamantina (Gorceix, 1884b, p. 1446; 1885a, p. 29–30) and in gold placers along tributaries to the Rio Doce near Casca (Gorceix, 1885a, p. 36), and to the State of Bahia in the vicinity of Salôbro (Gorceix, 1884b).

Some time between 1885 and 1890, John Gordon commenced to mine monazite sand on the coast of Bahia between Caravelas (Caravellas) and Prado. By 1890 when the local government temporarily halted the mining, according to Leonardos (1937a, p. 3), Gordon had shipped 15,000 tons of monazite concentrate to Europe. There is no independent verification of this estimate. In 1895 monazite mining was resumed, and 3,000 tons of concentrate produced in Bahia was exported during 1893-95 (Freyberg, 1934, p. 378). After 1895, beach placers were mined in Bahia, and new placers were opened in Espírito Santo and Rio de Janeiro along the Atlantic coast south of Bahia. Demand for monazite as a source for thorium and later for the rare earths (Drouin, 1911) led to a Brazilian output which reached a peak of 7,121 short tons in 1909 and totaled at least 85,827 tons by 1949 (Mertie, 1953, p. 6). After 1914 Brazil fell behind India as the leading producer of monazite.

Monazite marketed from Brazilian beach placers contains from 5.0 to 6.49 percent of ThO_2 (Copland, 1905, p. 6; Metall. and Chemical Eng., 1915, p. 403). Most writers are agreed that the Brazilian commercial monazite averages 6.0 percent of ThO_2 (Kremers, 1958, p. 2; Krusch, 1938, p. 73; Wadia, 1944, p. 6; Mattos Netto, 1951, p. 186; Johnstone, 1914, p. 58), but a slightly lower average of 5.5 percent of ThO_2 is favored by Barbosa (1948, p. 10). Representative commercial analyses are in the table that follows.

Several old analyses of monazite from the beaches of Espírito Santo show low abundances of thorium oxide compared to the average. A partial analysis of such material was made by Guilherme Florence in 1913 and was published by Furia (1939, p. 31). It showed 3.096 percent of ThO_2. Freise (1910a, p. 53–54) quoted an analysis given by Richardson in the Brazilian Mining Review for July 1903 which showed 1.48 percent of ThO_2 in a product obviously contaminated with quartz and zircon. Similar low abundances of thorium oxide were reported as far north as Bahia (Leonardos, 1937a, p. 12) for material called monazite or monazite sand which is of widely variable mineral composition. Radium was identified in salts from Brazilian monazite as early as 1904 (Haitinger and Peters, 1904).

Chemical analyses, in percent, of monazite from Brazilian beach placers

[Analysts: 1, F. H. Lee (in Metall. and Chemical Eng., 1915, p. 403); 2, Commercial average (in Kremers, 1958, p. 2); 3, Johnstone (1914, p. 58)]

	1	2	3
Ce_2O_3	31.28	62.00	66.12
$(La, Nd, Pr)_2O_3$	30.88		--------
Y_2O_3	--------		.80
ThO_2	6.49	6.0	6.06
P_2O_5	29.28	--------	28.50
SiO_2	1.40	--------	.75
Al_2O_3	--------	--------	.10
Fe_2O_3	--------	--------	.97
CaO	--------	--------	.21
Loss on ignition	.20	--------	.38
Total	99.53	--------	103.89

The immediate source of the monazite along the Atlantic beaches of Brazil are consolidated sedimentary rocks of Cretaceous age (Brazilian Eng. and Mining Rev., 1905, p. 153) and the Barreiras sedimentary series of Tertiary age (Oliveira, Avelino, 1956, p. 56–59). The ultimate source of the placer monazite is the plutonic complex of the Brazilian Shield.

CRYSTALLINE ROCKS AND FLUVIAL DEPOSITS

The crystalline rocks in Brazil were discovered early to contain accessory monazite. Derby (1889, p. 110) described how he had panned monazite from gneiss exposed in the Serra de Tijuca, at the city of Rio de Janeiro, and about a dozen places in the States of Rio de Janeiro, Minas Gerais, and São Paulo. Use of the gold pan to concentrate monazite led Derby and other geologists to discover the mineral in bedrock and stream sand not only in those states just mentioned and also in the States of Espírito Santo, Bahia, Paraíba, Rio Grande do Norte, Goiás, and Mato Grosso.

RIO DE JANEIRO

Gneiss, granite, and pegmatite are locally, possibly widely, monazite-bearing in the State of Rio de Janeiro. In the city of Rio de Janeiro, sillimanite-and cordierite-bearing gneisses contain monazite (Rimann, 1917, p. 21). Apatite-rich gneiss and silicic granite at Serra de Tijuca, a peak in the Serra do Mar near the city of Rio de Janeiro, and gneisses in the Serra do Mar were reported by Derby (1889, p. 110–112) to have monazite. The granite from Serra de Tijuca contains 0.02–0.03 percent of monazite (Hintze, 1922, p. 350; Moraes, Leonardos, and Lisbôa, 1937, p. 546). A monazite-bearing fine-grained granite dike is exposed near Jacarepagúa on the outskirts of the city of Rio de Janeiro (Derby, 1889, p. 113). The dike, which contains 0.07 percent of monazite and zircon, has the highest tenor in monazite of any rock examined by Derby (Hintze, 1922, p. 350). In the vicinity of Rio de Janeiro, monazite occurs as microscopic grains in granitic gneiss intruded by pegmatite at Niterói (Nitcheroy) (Leonardos, 1937a, p. 9) and in biotite granite which intrudes gneiss at Barra do Piraí (Barra do Piraley, Bassa do Pirahy). At this locality both the gneiss and the granite contain monazite (Derby, 1889, p. 113), but it is uncommonly abundant in the granite and is accompanied there by allanite (Hintze, 1922, p. 350). Monazite is virtually the sole accessory mineral accompanying massive graphite in a graphite-rich layer in gneiss at São Fidelis (Derby, 1902, p. 212). Granite at Consersatória (Conservatoria) was reported by Eugene Hussak (1891, p. 472) to contain monazite. In the same area at Santa Isabel do Rio Preto garnetiferous gneisses and samarskite-bearing pegmatite dikes have accessory monazite (Barbosa, C. D., 1948, p. 7, 9–10; Catriú, 1951, p. 290). Streams draining the area transport detrital monazite, garnet, and ilmenite. The detrital monazite contains 7.2–7.5 percent of ThO_2 (Barbosa, C. D., 1948, p. 10). Samarskite-bearing pegmatite dikes exposed around Paraibá do Sul, Rio Bonito, and Crubixais (Glícerio) contain small amounts of monazite (Catriú, 1951, p. 290).

SÃO PAULO

Monazite was found in crystalline rocks at many localities in São Paulo by Derby (1889, p. 111–113) following its initial discovery by Gorceix (1883, p. 32) in stream sand at the Fazenda Quebra–Cangalha. Monazite is an accessory mineral in sillimanite gneiss at Cotia (Cutia) and in syenite at San Joas. It occurs in muscovite granite at Caieiras in well-formed crystals 0.1 inch across (Hussak, 1891, p. 471). Muscovite granite at Sorocaba was found by Derby (1889, p. 111–112) to contain monazite. Biotite granite at Piedade, biotite-muscovite gneiss at Santos, and biotite granite and gneiss at Bôa Vista on the Rio Ribeira de Iguapa contain accessory monazite.

Accessory monazite eroded from granite gneiss and pegmatite occurs as a minor detrital constituent of continental sand and conglomerate of Tertiary and Recent age deposited in the upstream parts of the Rio Paraíba and Rio Paraibuna, and in the vicinity of São José dos Campos, São Paulo (Engenharia, Mineraçao e Metalurgia 1956; Leonardos, 1937a, p. 9). At Itapecerica da Serra (Itapecerica), detrital monazite was found at the base of sediments of Pliocene or Pleistocene age, and at various unspecified localities in the interior of São Paulo detrital monazite was observed in sand of Mesozoic age (Engenharia, Mineraçao e Metalurgia, 1956).

Monazite from decomposed granite at the Fazenda Recreio southeast of Pinhal, São Paulo, was analyzed about 1908 by Guilherme Florence and was found to contain 1.99 percent of ThO_2 (Furia, 1939, p. 31). The inner and outer parts of a large crystal of monazite from pegmatite at Grama, São Paulo, were analyzed for rare earths and thorium oxide in 1957. The original analyses of the core were published as percentages of the total rare earths plus thorium oxide precipitate equal 99.9 percent. The analysis was recalculated to 71.1 percent total rare earths plus thorium oxide in the monazite (H. J. Rose, Jr., written commun., 1958). The original analysis of the outer part was published as percentages of the total rare earths plus thorium oxide precipitate equal 100.4 percent. The analysis was recalculated to 70.74 percent total rare earths plus thorium oxide in the monazite (H. J. Rose, Jr., written commun., 1958). The core of the crystal contained 11.6 percent of ThO_2, and the outer part contained 10.93 percent:

Analysts: K. J. Murata and H. J. Rose, Jr. (in Murata and others, 1957, p. 148)]

	Percent	
	Core	*Outer part*
CeO_2	24.7	24.88
La_2O_3	8.1	8.46
Nd_2O_3	14.7	14.17
Pr_6O_{11}	3.7	3.73
Sm_2O_3	3.6	3.45
Gd_2O_3	1.6	1.76
Y_2O_3	3.1	3.36
ThO_2	11.6	10.93
Total	71.1	70.74

Another large crystal of monazite from a pegmatite at Grama contained 11.4 percent of ThO_2 (Murata, Dutra, and others, 1958, p. 7).

Attempts have been made to mine monazite from river sands in the interior of São Paulo, but the efforts were abandoned because the crude sand contained only 2 percent or less of monazite (Gottschalk, 1915, p. 903).

MINAS GERAIS

Crystalline rocks, particularly pegmatite, in the State of Minas Gerais have been extensively sampled, and monazite has been reported for many of these samples. The coastal range of Minas Gerais about 100 miles northwest of Rio de Janeiro exposes monazite-rich granite associated with gneiss and schist (Draper, 1911, p. 10). Sillimanite gneiss at Sossêgo (Socego) on the border between Minas Gerais and Rio de Janeiro contains monazite (Derby, 1889, p. 111-112).

Muscovite-bearing pegmatites at several localities in Município Juiz de Fora and the enclosing schists are monazite-bearing. Analyses of five samples of monazite taken between the wallrock and the quartz core of the pegmatite at the Roça Grande mine near Ibitiguaia disclosed that the ThO_2 ranged in abundance from 9.7 percent near the wallrock to 15.3 percent about halfway between the wallrock and the core and 11.4 percent adjacent to the core (Murata, and others, 1958, p. 7). The average abundance of ThO_2 was 11.6 percent. Monazite from the schist at the mine contained 3.3 percent of ThO_2. At a pegmatite in the Linhares mine in the same municipality, small monazite crystals near the wallrock contain 9.4 percent of ThO_2 (Murata and others, 1958, p. 7).

A layer of graphite in granitic gneiss cropping out in the bed of the Córrego do Emparedado about 65 miles downstream along the Rio Jequitinhonha from Arassuaí (Arassuahy) has abundant accessory monazite (Derby, 1902). The layer of graphite consists of 85 percent of carbon, 4.7 percent of volatile matter, and 7.2 percent of ash. The principal constituent of the ash is monazite. Derby noted that the monazite was in a state of strain and that it fell to pieces while he panned it out of the graphite. This occurrence and one of monazite-bearing graphite from gneiss near São Fidelis in Rio de Janeiro prompted Derby to investigate several samples of graphitic sericite schist from the two states. Inasmuch as he found no monazite in the graphitic sericite schist, whereas it was abundant in graphite layers from granite gneiss, Derby (1902, p. 212) concluded that the presence of monazite depended on the origin of the rock. He implied that monazite is present in graphite layers in gneisses of igneous origin and absent from graphite layers in schists of sedimentary origin. How the grade of metamorphism influences the amount of monazite seems not to have been considered by Derby.

Large crystals of monazite from pegmatite at Coronel Murta contain 9.1 percent of ThO_2 (Murata and others, 1958, p. 7).

The diamond-mining district of Diamantina, Minas Gerais, has many localities where monazite has been found. The district extends about 100 miles northeastward from Datas (Dattas) along the west side of the Rio Jequitinhonha. According to L. S. Thompson (1928, p. 707–709), schists of the basement complex in the Diamantina district, the Itacolomí series of late Precambrian age (Moraes and Guimarães, 1931, p. 503; Oliveira, Avelino, 1956, p. 19), are unconformably overlain by a cleaved and schistose quartzite which has a bed of conglomerate near the base. The conglomerate is 30–80 feet thick. It rests directly on the basement complex in the northern part of the district, but to the south around Datas the conglomerate is separated from the basement by at least 300 feet of quartzite lithologically identical to the overlying quartzite. Pebbles in the conglomerate have a wide range in composition, but quartz and quartzite are most common. The quartzite and conglomerate are part of the monazite- and diamond-bearing mesozonally metamorphosed Lavras series of Cambrian age (Moraes and Guimarães, 1931, p. 503; Leonardos, 1937a, p. 9; Oliveira, Avelino, 1956, p. 19–20).

The quartzite, conglomerate, and basement rocks are cut by mafic dikes and elliptically shaped masses of igneous breccia. The masses of breccia have nearly vertical walls and sharp contacts in the quartzite. The breccia consists of blocky fragments of quartzite in a matrix of mafic igneous rock similar to the dikes. Fragments of quartzite are oriented with their long axes parallel to the vertical walls of the breccia masses. No igneous alteration of the inclusions was seen. Unconformably overlying the quartzite, breccia, and mafic dikes are patches of poorly sorted conglomerate, sand, and silt of Tertiary or Pleistocene age. The rocks are thoroughly weathered to depths as great as 300 feet below the present surface of the land.

Mafic dikes exposed in the Barro-Duro opencut near São João da Chapada in the Diamantina district were reported by L. S. Thompson (1928, p. 709) to contain monazite. Sheared diabase and soft greenish schist from a mine at São João da Chapada, probably the same opening visited by Thompson, had previously been found by Derby (1899, p. 348; 1900a, p. 209–213) to be monazite-bearing. The concentrate obtained by Thompson consisted of rutile, anatase, ilmenite, kyanite, tourmaline, monazite, and magnetite. None of the minerals was abraded. A similar concentrate was panned by Thompson from the matrix of one of the igneous breccias. Derby remarked that the greenish schist had practically no free quartz and that similar monazite-bearing mafic dikes were exposed near Datas at the south end of the district. These were the only outcrops of mafic rocks in Brazil from which Derby obtained monazite. He regarded the occurrences as unlike any elsewhere reported.

Partially altered and corroded crystals of monazite and xenotime were recovered from the heavy residues of lazulite-rich nodules in the quartzite in the Diamantina district (Derby, 1891a; 1891b; 1899, p. 350–351). Derby thought that the lazulite, which is a common secondary mineral in the quartzite, might have been liquid inclusions.

In the Perpetua deposit at São João da Chapada, diamondiferous sericite phyllite formed by cataclastic deformation and alteration of laminated, conformable, muscovite-bearing granitic rock intrusive into the Itacolomí series contains abundant accessory hematite, and less common magnetite, tourmaline, monazite, xenotime, and rutile. The relative abundance of the main accessory minerals is shown by the composition of a concentrate panned from 20 cubic meters of rock from which 2 carats of diamonds were recovered (Morase and Guimarães, 1931, p. 524):

	Percent
Quartz	30. 9
Hematite	62. 7
Magnetite	1. 0
Tourmaline	1. 1
Monazite	4. 3

The monazite in this materail consists of crystal fragments thought by Moraes and Guimarães to have been formed during the cataclastic deformation of the original granitic rock.

Other rocks in the district that contain monazite are chlorite-kyanite phyllite or schist which crops out near the Serra do Gigante several miles to the north of São João da Chapada and saprolite of sericite schist from Sopa (Derby, 1899, p. 348–351; 1900b, p. 220). The phyllite contains many enormous crystals of kyanite in an imperfectly laminated groundmass of chlorite. The rock is rich in monazite, and the monazite, like the chlorite and kyanite, contains numerous minute grains of rutile. The sericite schist at Sopa may be the metamorphic derivative of a porphyry (Derby, 1900b, p. 221). Near the large diamond mine at São João da Chapada in a small gold mine called Ogó, monazite is associated with rutile and bright green muscovite in a quartz vein in diabase. Auriferous quartz veins in the neighborhood of Diamantina, which, according to Hintze (1922, p. 354–355), are probably genetically related to pegmatitic granite, contain thorium-bearing monazite full of gaseous and derived from original clastic phosphate.

A gold placer at Bandeirinha on the Riacho Varas in the vicinity of Sopa and São João da Chapada contains monazite of a peculiar prismatic habit which is filled with scales of hematite and minute needles of rutile (Derby, 1900b, p. 219; Smith, H. C., 1896, p. 372; Hintze, 1922, p. 354). The monazite was traced by Derby to sericite phyllite. In the placer the monazite is accompanied by crystalline unrounded gold, euhedral xenotime, prismatic colorless zircon, needles of black tourmaline, limonitized pyrite, magnetite, and mica (Hussak and Reitinger, 1903, p. 560). An average of two analyses of the monazite showed that it contained 1.09 percent of ThO_2 and that it had a specific gravity of 4.96; monazite from the valley of the Riacho Varas was said to contain no thorium and had a specific gravity of 5.2:

[Analyst: *A*, J. Reitinger (in Hussak and Reitinger, 1903, p. 560); *B*, J. Reitinger (in Hintze, 1922, p. 370)]

	Percent	
	A	*B*
Ce_2O_3	32. 46	33. 9
$(La, Pr)_2O_3$	19. 21	36. 6
Nd_2O_3	16. 81	
ThO_2	1. 09	. 00
P_2O_5	29. 18	30. 00
Fe_2O_3	. 61	-------
CaO	. 10	-------
Total	99. 46	100. 5

A. Bandeirinha. Average of two analyses.
B. Riacho Varas.

Concentrates containing possibly 80 percent of monazite and said to have come from a stream in the Diamantina area have 11.16 percent of ThO_2, 24.57 percent of P_2O_5, 29.49 percent of Ce_2O_3, 3.62 percent of La_2O_3 (group) and 10.96 percent of SiO_2 according to an incomplete analysis given by Freise (1911, p. 258).

Elsewhere in the Diamantina district, monazite has been reported from undescribed bedrock, diamond mines, and stream sediments at Pagão, Campo do Sampaio, Perpetua (Moraes, Barbosa, and others, 1937, p. 132), and Milho Verde in the headwaters of the Rio Jequitinhonha where that river is called the Rio das Pedras (Gorceix, 1884a, p. 182; 1885a, p. 29).

Monazite, according to L. S. Thompson (1928, p. 709), is a rare member of a group of minerals that accompanies diamonds wherever they are found in the Diamantina district. Other rare members of the group are zircon, staurolite, and corundum. Quartz crystals, opalescent quartz, rutile, anatase, ilmenite, and kyanite are the common minerals associated with the diamonds, and less commonly magnetite, hematite, garnet, and tourmaline appear. These minerals are said by Thompson to be rolled and worn in appearance where they are derived from placers regardless of the age of the placer, and they are said to have a fresh, clear-cut appearance where derived from the diamondiferous igneous breccias and dikes. Placers of at least three ages are recognized by L. S. Thompson (1928, p. 709). The youngest are alluvial placers in the terraces, flood plains, and beds of the present streams, and eluvial placers in the residual soil. Somewhat older deposits are the fossil placers in sediments of Tertiary or Pleistocene age. The oldest deposits are the fossil placers in the quartzite. Thompson's generalization that only round and abraded heavy minerals are found in the present alluvium and in the old quartzite is, with respect to monazite, not entirely in accord with the observations of other writers (Derby, 1898).

Good crystals of monazite, as much as 0.4 inch long, have been taken from the diamond-bearing alluvium at Datas and were used by Busz (1914, p. 482–483) for a study of the form and optical properties of monazite. In a gold placer at Bandeirinha, mentioned above, prismatic crystals of monazite are accompanied by unrounded crystals of gold (Derby, 1900b, p. 219; Hussak and Reitinger, 1903, p. 560).

A clear description of the fresh appearance of monazite from metamorphosed conglomerate at the Cavallo Morto diamond mine near Diamantina was given by Derby (1900b, p. 218–219). His observations of monazite in the Cavallo Morto mine and in chlorite-kyanite phyllite at the Serra do Gigante led him to conclude that monazite can form both as an igneous and as a metamorphic mineral (Derby, 1900b, p. 219–220). This important inference was subsequently ignored.

The Diamantina area is evidently one in which monazite has a wide variety of habitat including unusual occurrences in mafic rocks, low- and high-rank metamorphic rocks, veins, and lazulite nodules.

The pegmatite districts of Minas Gerais have supplied many samples of monazite for study, but they apparently include no commercial monazite deposits. Cassiterite- and tantalite-bearing pegmatite dikes in the São João del Rei area of Minas Gerais contain monazite (Belezkij, 1956, p. 2–15;; Guimarães and Belezkij, 1956; Guimarães, Djalma, 1956; Rolff, 1947; 1948, p 16; Vaz, 1948, p. 26). The dikes are emplaced in granite gneiss and gneiss. According to Belezkij, cassiterite is the principal economic mineral in the district, and most of the cassiterite is in pegmatite in the basin of the Rio das Mortes west of the city of São João del Rei. Around the city auriferous quartz veins are common, and north of the city in the vicinity of Santa Rita do Rio Abaixo are stanniferous pegmatite dikes and veins containing monazite, xenotime, and fergusonite. Medium-grained light-gray gneissic granite exposed on the Morro do Rezende and in the Rio das Mortes contains monazite (Belezkij, 1956, p. 6–9). The rock consists of quartz, biotite, microcline, oligoclase, albite, monazite, titano-magnetite, sphene, epidote, zoisite, muscovite, and zircon. The monazite and zircon are rounded and are included in the other minerals. Because of the round shape of the zircon and monazite, and the abundance of quartz in the rock, the gneiss is said to have been metamorphically derived from an arenaceous tuffaceous sediment under mesozone conditions and subsequently granitized. Questionably identified monazite was seen by Belezkij (1956, p. 15) in cataclastic biotite gneiss exposed between the village of Cassiterita and the Rio das Mortes Pequeno.

Large crystals of monazite from a pegmatite in the São João del Rei district contain 17.0 percent of ThO_2 (Murata and others, 1958, p. 7).

Eluvial monazite concentrate from the Fazenda da Barra on the Rio das Mortes in the São João del Rei district was analyzed by Peixoto and shown to have 6.22 percent of ThO_2 where fresh and 5.73 percent where somewhat weathered (Peixoto and Guimarães, 1953, p. 24):

	Percent	
	Fresh	*Weathered*
Ce_2O_3	38.08	---------
La_2O_3	9.53	---------
Gd_2O_3	Trace	---------
Y_2O_3	10.15	---------
ThO_2	6.22	5.73
U_3O_8	Trace	0
P_2O_5	25.75	---------
SiO_2	1.09	---------
Al_2O_3	.49	.90
FeO	2.07	---------
TiO_2	.17	---------
CaO	.02	---------
MgO	Trace	---------
MnO	.29	---------
PbO	.16	.15
SnO	.33	---------
ZrO_2	Trace	---------
Ta_2O_5	.64	---------
Nb_2O_5	4.72	---------
K_2O+Na_2O	Trace	---------
H_2O	.40	.60
Total	100.11	---------

Samples of monazite from pegmatite, eluvium, and alluvium in the São João del Rei area were analyzed for thorium oxide by Alexandre Girotto with the following results (Rolff, 1948, p. 18):

	Source	ThO_2 *(percent)*
Fazenda Rochedo	Pegmatite	10.80
Ribeirão Jaburu	Eluvium	8.74
Fazenda Fundão	Eluvium	9.32
Mato Virgem	Pegmatite	7.00
Ibatuba (Soledade)	Pegmatite	7.66
Ibatuba	Eluvium	6.85
Ibatuba	Alluvium	7.50

Placers throughout the São João del Rei area contain monazite derived from the gneiss, granite, pegmatite, and veins. Monazite from a stream at Ibatuba was reported to have the following composition:

[Analyst: C. M. Pinto (in Araújo, 1948, p. 48)]

	Percent		Percent
Ce_2O_3	28.50	Al_2O_3	0.21
$(Nd, Pr)_2O_3$	29.20	Fe_2O_3	.65
$(Y, Er)_2O_3$	3.80	CaO	.36
ThO_2	7.60	Loss on ignition	1.36
P_2O_5	24.80		
SiO_2	2.95	Total	99.43

A rather similar analysis was reported for monazite from Minas Gerais, but the exact geologic and geographic source was not given:

[Analyst: Kato (1958, p. 226)]

	Percent		Percent
Ce_2O_3	28.43	Fe_2O_3	2.88
La_2O_3	32.49	CaO	.02
ThO_2	5.37	PbO	.09
U_3O_8	Trace	Loss on ignition	.46
P_2O_5	28.57		
SiO_2	1.18	Total	100.57
Al_2O_3	1.08		

Monazite from pegmatite at Rochedo, Município de Resende Costa, Minas Gerais, includes minute grains of tantalite, cassiterite, and feldspar and contains as much as 9.19 percent of ThO_2:

[Analyst: Peixoto (in Peixoto and Guimarães, 1953, p. 22)]

	Percent		Percent
Ce_2O_3 (group)	55.60	CaO	0.06
La_2O_3	Trace	MgO	.06
ThO_2	[1] 9.19	MnO	.01
U_3O_8	.12	PbO	[2] .44
P_2O_5	26.33	SnO_2	.63
SiO_2	.35	$Ta_2O_5+Nb_2O_5$	1.98
Al_2O_3	4.18	H_2O	[3] 1.10
Fe_2O_3	4.04		
TiO_2	.02	Total	[4] 104.11

[1] Weathered sample contains 8.88 percent of ThO_2.
[2] Weathered sample contains 0.41 percent of PbO.
[3] Weathered sample contains 1.47 percent of H_2O.
[4] Given as 100.11 percent.

Monazite is associated with beryl, columbite, and annerodite in a pegmatite dike at Gruta da Generosa near Sabinópolis (Leonardos, 1936a; 1936b, p. 16–17; 1937a, p. 9; Catriú, 1951, p. 289). The dike is 10 feet thick, is emplaced in biotite gneiss, and consists of microcline-perthite and a quartz core. Books of muscovite accompany the feldspar. Monazite is thought by Leonardos to have been the first mineral to crystallize, and it was followed by columbite, annerodite, beryl, muscovite, microcline, fluorite, and quartz. Although monazite makes up less than 0.01 percent of the pegmatite, some crystals of monazite weigh as much as 2.5 pounds. The monazite is rich in thorium oxide, but an early analysis cited by Leonardos that showed 20.2 percent of ThO_2 is not supported by later analyses given by Peixoto and Guimarães and Murata and associates, which show 8.02–9.4 percent.

Chemical analyses, in percent, of monazite from Gruta da Generosa

[Analysts: 1, Escola de Minas de Ouro Preto (in Leonardos, 1936a, p. 16); 2–4, Peixoto (in Peixoto and Guimarães, 1953, p. 23); 5–6. Murata, Dutra, Costa, and Branco (1958, p. 7). Symbol used: --, not determined]

	1	2	3	4	5	6
Ce_2O_3	} 51.06	34.40	--	--	--	--
La_2O_3		29.44	--	--	--	--
Y_2O_3	--	.35	--	--	--	--
ThO_2	20.20	8.55	8.16	8.02	9.4	8.7
U_3O_8	.16	.30	.20	.19	--	--
P_2O_5	22.21	22.23	--	--	--	--
SiO_2	3.28	2.12	--	--	--	--
Al_2O_3	--	.89	1.07	1.21	--	--
FeO	--	.26	--	--	--	--
Fe_2O_3	1.46	--	--	--	--	--
TiO_2	--	.19	--	--	--	--
CaO	--	.07	--	--	--	--
MgO	--	.02	--	--	--	--
MnO	--	.01	--	--	--	--
PbO	--	.09	.10	.10	--	--
SnO_2	--	.09	--	--	--	--
BeO	--	Trace	--	--	--	--
K_2O	--	.03	--	--	--	--
H_2O	1.62	.29	--	--	--	--
Total	99.99	99.33				

A weathered pegmatite in the Divino de Ubá district, Minas Gerais, has been mentioned several times in the literature for its large crystals of monazite. As originally described by Djalma Guimarães (1925, p. 115–117), the vein was said to intrude bedded biotite quartzite and mica schist. It has a quartz core and kaolinized walls. Muscovite is common in the walls, and radiating crystalline aggregates of samarskite, columbite, and monazite occur with the muscovite. In a later description of the deposit, Leonardos (1936b, p. 22–25) stated that in the radial aggregates the samarskite, monazite, and columbite have proportions of 75, 15, and 10 percent, although an earlier account (Fenner, 1928, p. 383) mentioned that columbite predominates over samarskite and monazite. In any event the monazite forms exceptionally large crystals some of which weigh as much as 1.5 pounds (Leonardos, 1936b, p. 22–25). Djalma Guimarães (1925, p. 118) reported that the monazite contained about 18.00 percent of ThO_2 and 70.67 percent of RE_2O_3.

This estimate of the amount of thorium oxide, though later cited by C. D. Barbosa (1948, p. 7) and Leão (1939, p. 164), is most certainly incorrect. Excellent analyses for thorium oxide were made on this material by Fenner (1928, p. 386), who took special care to prepare clean, fresh samples of the monazite. Fenner made four analyses which showed 5.78, 5.68, 5.78, and 5.93 percent of ThO_2 and averaged 5.79 percent of ThO_2. The monazite also contained 0.06 percent of U_3O_8. Leonardos (1936b, p. 22–25) wrote that the monazite from Divino de Ubá contains 70–76 percent of RE_2O_3 and 6–8 percent of ThO_2 and that it has a specific gravity of 5.25. A recent analysis by Murata, Dutra, Costa, and Branco (1958, p. 7) showed 6.3 percent of ThO_2.

Monazite-bearing weathered pegmatite dikes are found around Brejaúba, Minas Gerais, at São José do

Brejaúba (Guimarães, Djalma, 1925, p. 116), and at the Fazenda da Posse (Guimarães, C. P., 1939, p. 35). At Fazenda da Posse the pegmatite consists of microcline and quartz plus a complex paragenetic sequence of minerals among which are muscovite, bismuthinite, beryl, garnet, columbite, magnetite, samarskite, djalmaite, tourmaline, and monazite. Monazite from the pegmatites is said to be rich in thorium oxide (Leonardos, 1937a, p. 9), and an analysis shows 6.7 percent of ThO_2 (Murata and others, 1958, p. 7). Monazite from a nearby pegmatite contains 13.7 percent of ThO_2 (Murata and others, 1958, p. 7). Monazite taken from small stream placers in the area is reported to contain from 0 to 12 percent of ThO_2 (Barbosa, C. D., 1948, p. 7). The wide range in the amount of thorium oxide in the placer monazite is unusual, and the absence of thorium oxide in some samples indicates source rocks other than pegmatite in the Brejaúba area.

Monazite from pegmatite dikes around Ferros, including large crystals in pegmatite at Lambray de Ferros (Leonardos, 1937a, p. 9) is rich in thorium oxide. Monazite from pegmatite at Ferros, Minas Gerais, was found to have the following composition:

[Analysts: Murata and Rose (in Murata and others, 1953, p. 294)]

	Percent
CeO_2	28.78
La_2O_3	9.25
Nd_2O_3	15.98
Pr_6O_{11}	3.83
Sm_2O_3	3.48
Gd_2O_3	1.04
Y_2O_3	.77
ThO_2	7.85
Total	70.98

The original analysis was published as percentages of the total rare earths plus thorium oxide precipitate equal 102.1 percent. Here recalculated to 70.98 percent total rare earths plus thorium oxide in the monazite (H. J. Rose, Jr., written commun., 1958). Later analyses of other crystals of monazite from pegmatites at Ferros disclosed 10.0 and 8.0 percent of ThO_2 (Murata and others, 1958, p. 7).

Large crystals of thorium oxide-rich monazite are in pegmatite dikes at Presidente Vargas (Itabira) (Leonardos, 1937a, p. 9). Scarcely abraded detrital monazite occurs with anatase, rutile, ilmenite, magnetite, hematite, martite, tuormaline, kyanite, sillimanite, diamonds, and gold in streams at Barão de Cocais, Minas Gerais (Hintze, 1922, p. 354).

Pegmatite at Lima Duarte contains large crystals of thorium oxide-rich monazite, and, in the streams about 60 miles to the east around São José de Além Paraíba, detrital monazite has been found (Leonardos, 1937a, p. 9).

Monazite was identified by Hussak (1909) in concentrates panned from a small mica-rich phenacite-bearing pegmatite vein exposed in the San Miguel de Piracicaba gold mine at Piracicaba, Minas Gerais. Other minerals in the concentrate were amazonite, mica, black tourmaline, zircon, columbite, hematite, pyrite, almandine, and xenotime.

A pegmatite dike in muscovite schist 10 miles northeast of São Sebastião do Rio Prêto in the Conçeicão district, Minas Gerais, contains abundant beryl and sparse monazite, columbite, samarskite, betafite, and bismuth minerals (Leonardos, 1936b, p. 15). Gold-bearing quartz veins at Passabem (Passagem) in the same area are reported to contain scarce dark-yellow crystals of monazite (Derby, 1899, p. 345; Bensusan, 1910, p. 6; Hintze, 1922, p. 355; Wichmann, 1927, p. 22–24; Gregory, 1948, p. 488). The monazite occurs in auriferous aggregates of arsenopyrite and tourmaline in the quartz veins.

Monazite crystals as much as 0.1 inch in length and full of inclusions of magnetite have been found in a tungsten mine at Tripuhy near Ouro Preto, Minas Gerais (Hintze, 1922, p. 355). The deposit is in weathered mica schist which grades into itabirite. Apparently the rocks were once strongly pyritized, and the pyrite has altered to limonite. The weathered schists are covered with a thick mantle of sand in which cinnabar, monazite, lewisite, xenotime, zircon, kyanite, tourmaline, rutile, hematite, pyrite, magnetite, gold, tripuhyite, and a titanantimonate occur (Hussak and Prior, 1897). The schists contain monazite (Derby, 1899, p. 352).

The distribution and composition of monazite across a zoned pegmatite at the Emprêsa Caolim mine in the Estêvão Pinto district, Município Mar de Espanha were described by Murata, Dutra, Costa, and Branco (1958, p. 4, 9–12). They found systematic variation in distribution and composition which they interpreted to indicate fractionation of the elements during crystallization with enrichment of thorium in the residual fluids. Crystals of monazite from the wall zones of the pegmatite contained from 6 to 7 percent of ThO_2 and crystals near the quartz core contained 9.1–12.2 percent of ThO_2. Average abundance of ThO_2 for nine samples was 7.9 percent. Monazite from the schist forming the wallrock contained 6.1 percent of ThO_2.

Monazite derived from the crystalline rocks is found in many of the streams in Minas Gerais. The stream deposits are shallow, and no mining industry has developed on them (Gottschalk, 1915, p. 903), although

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some mining has been attempted along the banks of the Rio Paráiba at the Barra São Francisco near Sapucaia, Minas Gerais, where large deposits of black sand contain a trace of monazite (Kithil, 1915, p. 14; Freyberg, 1934, p. 376). Kithil (1915, p. 13–14) likened the stream placers in Minas Gerais to those in the Carolinas, because they are in small creeks and bottomlands in a region of deeply weathered bedrock. His estimate that gravel in streams in Minas Gerais contains only 0.25–0.3 percent of monazite is nearly an order of magnitude lower than Gottschalk's (1915, p. 903) estimate of a maximum of 2 percent of monazite in alluvium in São Paulo, but it agrees closely with earlier findings reported by Freise (1910a, p. 63). Reports by Moravia (1909, p. 39–40), and Freyberg (1934, p. 376) showed that stream sand at the Fazenda da Arribada near Mar de Espanha contained 1 percent of monazite and 0.5 percent of xenotime in large crystals, and that especially rich sand at the Fazenda Campos Elysios, also near Mar de Espanha, contained as much as 50 percent of monazite having from 4.0 to 5.7 percent of ThO_2. Coarse-grained sediments are richer than fine-grained sediments at Mar de Espanha, and old deposits are richer than reworked new deposits. Small stream placers commonly have local enrichments of this sort. They have received comment from many parts of the world but have failed to sustain mining except in the Carolinas.

Placer monazite from streams in the interior of Brazil was thought by Kithil (1915, p. 19) to contain an average of 4.5 percent of ThO_2, but it seems to the writer far more likely that the average is closer to the 6.0 percent of ThO_2 generally accepted for monazite in the Brazilian beach placers (Schreiter, 1922, p. 40). Obviously a wide range in the abundance of thorium oxide in detrital monazite can be cited for Minas Gerais, as, indeed, has already been done in this text. A general average would have little meaning in the economics of the stream placers.

The most detailed study of monazite in stream placers in Brazil was by Freise (1910a). He examined 236 placers in an area covering about 1 square degree in the drainage basins of the Rio Pomba and Rio Muriahé near the border between Minas Gerais and Espírito Santo. In the northern part of the area around the Serra do Tombas and Serra do Papageios, the bedrock is veined gneiss and schist with some interlayered quartzite. A few cordierite and sillimanite schists are locally present, and granite veins are common. In the southern part of the area, some diorite crops out. Pegmatite dikes at the Fazenda Santa Clara near Pomba are monazite-bearing (Catriú, 1951, p. 289). They also contain samarskite, polycrase, and xenotime. Small crystals from these pegmatites contain 6.6 percent of ThO_2 and large crystals contain 5.3 percent (Murata and others, 1958, p. 7).

The placers are in stream sediments which rest on the planed and weathered bedrock of the flat valley floors. Directly on bedrock at the base of the stream sediments is a discontinuous layer of gravel 0.2–8 feet thick. A matrix of clay and sand binds the gravel, which includes fragments of rock as much as 3 feet in diameter. About 40 percent of the placer area contains gravel. Ordinarily there is one layer of gravel in a deposit, and it is the source of placer monazite. At some places there are three to five beds of gravel all of which contain monazite. Overlying the gravel, or resting on bedrock where no gravel is found, is 0.4–7 feet of quartz sand and clay in which there are veins of limonite. From 1 to 3 feet of muck overlies the sand and clay. This overburden is lean in monazite.

The placers were sampled by Freise (1910) from 1,553 pits and 1,801 boreholes. From these openings, 6,238 samples were taken. Heavy-mineral concentrates were panned from the samples, and the identity and relative abundance of the minerals associated with detrital monazite in the drainage basins of the Rio Pomba and Rio Muriahé, Minas Gerais, Brazil, were determined under the microscope. The following minerals were identified:

Aeschynite	Fergusonite	Pyrrhotite
Amphibole	Fluorite	Quartz (seven varieties)
Andalusite	Gold	Rutile
Anatase	Hematite	Samarskite
Apatite	Hessonite	Sillimanite
Axinite	Ilmenite	Sphene
Auerbachite	Kyanite	Thorite
Beryl	Magnetite	Topaz
Biotite	Mosandrite	Tourmaline
Cassiterite	Muscovite	Vesuvianite
Chrysoberyl	Olivine	Wolframite
Columbite	Orangite	Xenotime
Cordierite	Pleonaste	Zircon
Corundum	Pyrite	
Epidote	Pyrochlore	
Euxenite	Pyrope	

Of the 46 minerals found to be associated with the detrital monazite only 12 are common: quartz (seven varieties), gold, magnetite, ilmenite, rutile, tourmaline, zircon, garnet (two varieties), olivine, amphibole, biotite, and muscovite. In a sampling of 3,000 of the concentrates, the abundance of the rare-earth- and thorium-bearing minerals other than monazite, compared to the abundance of monazite in each sample as 100 percent, showed thorite 12 percent, xenotime 5 percent, pyrochlore 3 percent, aeschynite 0.5 percent, and orangite 0.5 percent.

Characteristic mineral assemblages were found in placers formed on specific kinds of rocks. Association of monazite with tourmaline, amphibole, and olivine was typical in areas underlain by gneiss and diorite. Association of monazite with zircon was common in areas where granite was exposed. Association of monazite with garnet predominated in areas of gneiss. Mica, ilmenite, and gold were found in all assemblages.

The size distribution of grains in samples from 0.5 short ton of monazite concentrate from the Rio Pomba area was measured by Freise (1910a, p. 53). He found that 63.4 percent of the grains were less than 0.5 mm in maximum intermediate dimension:

Size (mm)	*Percent*
>2. 5	6. 3
1. 5–2. 5	12. 4
. 5–1. 5	17. 9
. 2– . 5	26. 3
<. 2	37. 1
Total	100. 0

The size distribution among the particles in the concentrate seems to reflect the sizes of the grains as they came from the parent crystalline rocks, because the grains have been transported but little from their source and are but slightly abraded. The concentrate, however, is far from monomineralic. Analyses by Freise (1910a, p. 53; 1911, p. 258) of concentrates from the Rio Muriahé and Rio Pomba show large amounts of ZrO_2, TiO_2, SiO_2, and insoluble material:

	Percent	
	Rio Muriahé	*Rio Pomba*
Ce_2O_3	36. 42	36. 12
$(La, Nd, Pr)_2O_3$	3. 94	5. 57
ZrO_2	16. 28	---------
ThO_2	3. 85	. 83
Fe_2O_3	2. 04	1. 12
Al_2O_3	1. 36	---------
TiO_2	4. 56	---------
P_2O_5	19. 65	---------
Ta_2O_5	. 12	---------
SiO_2	7. 03	13. 69
Insoluble residues	4. 75	---------
Total	100. 00	---------

Among the 236 deposits examined by Freise, 177 placers were favorably appraised. The total area of the 177 placers was 218 million square yards of which about 81 million square yards was underlain by gravel. The gravel, however, was remarkably shallow. It was estimated to have an average thickness of 0.33 foot and a total volume of 9 million cubic yards. About 66,000 short tons of monazite was inferred to be in the gravel. Thus, the average tenor of the gravel in the 177 placers was 15 pounds of monazite per cubic yard. No record can be found of the amount of monazite shipped from the Rio Pomba district, which leads to the inference that the stream placers contributed little if anything to the total Brazilian output of monazite.

Detrital monazite is in sediment of the Rio Casca, a tributary to the Rio Doce near Casca, Minas Gerais, where it accompanies almandine, gold, amethyst, and scarce zircon. The heavy minerals are derived from quartzite and mica schist extensively veined by quartz. Tourmaline, garnet, pyrite, and arsenopyrite commonly occur in the quartz (Gorceix, 1885a, p. 35–36; Smith, H. C., 1896, p. 372). An early analysis by Gorceix (1885a, p. 36), in which the thorium may not have been determined, showed 31.5 percent of P_2O_5, 36.8 percent of CeO, and 31.5 percent of DiO plus LaO in monazite from the Rio Casca placers.

The Córrego da Onça—one of many small streams by that name in Minas Gerais—near Itarana (Figueira) and tributary to the Rio Doce (Jacob, 1916) contains small amounts of detrital monazite derived from decomposed mica schist and gneiss. An analysis was made of this monazite with the following results:

[Analyst: Guilherme Florence in 1908 (in Furia, 1939, p. 31)]

	Percent		*Percent*
$(Ce, La, Nd, Pr)_2O_3$	62. 48	ZrO_2	0. 40
ThO_2	5. 72	CaO	1. 37
P_2O_5	28. 42	MgO	. 04
SiO_2	. 74		
Al_2O_3	. 37	Total	99. 87
Fe_2O_3	. 33		

The monazite-bearing headwaters of the Rio Mucuri (Rio Mucury) and Rio Jequitinhonha between Teófilo Otoni (Theóphilo Ottoni) and Arassuaí (Arassuahy) drain strongly gneissic biotite granite cut by dikes of pegmatite (Moraes, Barbosa, and others, 1937, p. 131; Freyberg, 1934, p. 371–372; Hintze, 1922, p. 356). Coarse monazite, muscovite, tourmaline, and beryl are associated in the pegmatite with sparse xenotime, aeschynite, phenacite, and thorite. Masses of monazite which weigh as much as 2 pounds have been found in the pegmatite. An analysis of material from a pegmatite, identified as monazite but which was possibly a mixture of monazite, aeschynite, zircon, and quartz, totaled only 94.11 percent and showed 31.21 percent of Ce_2O_3, 9.23 percent of ThO_2, 28.36 percent of P_2O_5, 10.14 percent of SiO_2, 0.32 percent of Al_2O_3 4.22 percent of Fe_2O_3, 2.62 percent of TiO_2, 5.74 percent of ZrO_2, 1.16 percent of Ta_2O_5, and 1.11 percent of CaO (Freyberg, 1934, p. 372). Analyses of monazite concentrates from streams in the area show less thorium oxide. Freyberg (1934, p. 376) stated that monazite concentrates of unspecified mineralogical composition from the Rio Mucuri and Ribeirão Barro Preto in the vicinity of Teófilo Otoni contain only 4.10 percent of ThO_2. Concentrates containing 90 percent of monazite, made from sand in the Córrego das Americanas near Teófilo Otoni, were said by Moraes, Barbosa, Arrojado Lisbôa, and Lacourt (1937, p. 131) to have 6 percent of ThO_2. This analysis suggests that detrital monazite from the region contains about 6.7 percent of ThO_2.

The abundance of monazite in the streams around Teófilo Otoni varies locally from 5 percent of the sand, in the vicinity of the town, to 1.5 percent of the sand, near the junction of the Rio Mutum with the Rio Mucuri, and in the Córrego das Americanas, Córrego da Onça, and Córrego do Surucucú, and generally 1 percent of the sand, in the Rio Mucuri (Moraes, Barbosa, and others, 1937, p. 131–132; Hintze, 1922, p. 356). Other heavy minerals in the sands include magnetite, topaz, garnet, tourmaline, cassiterite, chrysoberyl, rutile, and ilmenite. Monazite is most abundant in the streams that have the least amount of magnetite, ilmenite, and rutile.

Gneiss and pegmatite are exposed in the basin of the Córrego do Sobrado about 2 miles south of Rio do Peixe in the Município de Passa Tempo, Minas Gerais. Alluvial and eluvial deposits in the basin contain round grains of monazite. A concentrate panned from alluvium was reported by Peixoto and Guimarães (1953, p. 13) to consist of the following:

	Percent
Quartz	26.0
Monazite	14.8
Zircon	2.2
Ilmenite	11.8
Magnetite	44.9
Sillimanite	.3
Total	100.0

An analysis of the monazite was made by Peixoto and disclosed that it contained 10.17 percent of ThO_2:

[Analyst: Peixoto (in Peixoto and Guimarães, 1953, p. 32)]

	Percent		*Percent*
Ce_2O_3 (group)	39.93	TiO_2	0.59
La_2O_3	16.08	CaO	.12
Y_2O_3 (group)	.88	MgO	.06
ThO_2	10.17	MnO	Trace
U_3O_8	None	PbO	.79
P_2O_5	24.25	ZrO_2	Trace
SiO_2	2.24	H_2O	.80
Al_2O_3	1.06		
FeO	3.26	Total	100.23

ESPÍRITO SANTO

The monazite in crystalline rocks in the State of Espírito Santo has received but little mention in the literature. It is far overshadowed by discussions of monazite in the famous beach placers. A few localities, however, have been described. Monazite-bearing gneissic biotite granite crops out in the highlands that form the border with Minas Gerais. Monazite has been found from the area between the Rio Mutum in Minas Gerais and the Rio Pancas in Espírito Santo to the junction of the Rio São João with the Rio Doce. The granite gneiss around the Rio São João has augen of garnets and rutile and is cut by pegmatite dikes. Large masses of monazite in the pegmatite dikes display many fine cleavage cracks filled with xenotime, aeschynite, and phenacite (Hintze, 1922, p. 356).

The Serra dos Aimorés and Serra da Liberdade on the border between Espírito Santo and Minas Gerais, underlain by monazite-bearing gneisses and pegmatite dikes, constitute about half of the upper drainage basin of the Rio São José (Erichsen, 1948, p. 77; Freyberg, 1934, p. 371). This stream is the principal source of Lagoa Juparanã, Espírito Santo, which has appreciable amounts of monazite and ilmenite along its shores (Erichsen, 1948, p. 77). An impure monazite concentrate from a pegmatite vein exposed in the southern part of the Serra dos Aimorés contains 9.23 percent of ThO_2 (Freise, 1911, p. 258). Between 65 and 70 percent of the concentrate appears to have been monazite; therefore, the monazite may have as much as 14 percent of ThO_2.

A coarsely crystalline aggregate of magnetite and ilmenite from a mica syenite at the Fazenda Catita on the lower Rio Doce, Espírito Santo, contained monazite, zircon, corundum, and biotite (Derby, 1902, p. 211). The monazite occurs as isolated crystals in the iron oxides and biotite.

At Guarapari, pegmatite dikes intrude amphibolite and biotite gneiss. The dikes contain accessory garnet, ilmenite, monazite, and zircon (Moraes and others, 1937, p. 547; Nova, 1945, p. 282).

BAHIA

The State of Bahia, also, is rarely cited for monazite-bearing crystalline rocks, although the famous coastal placers are often mentioned.

Grains of monazite have been observed (Leonardos, 1937a, p. 9) in a sequence of mesozonally metamorphosed diamondiferous tillite, sandstone, and conglomerate at Salôbro and Lencóis (Lençoes). Monazite was originally deposited as detrital grains with the sediments, which are a part of the Lavras series of quartzite and conglomerate of Cambrian age (Oliveria, A. I. de, 1956, p. 19–20). After metamorphism, uplift, and exposure, the series was deeply weathered and eroded. This weathering and erosion released diamonds from the rocks, and placer deposits formed. Monazite is found in the placers. The monazite consists of practically unabraded crystal *fragments*, some of whose surfaces are encrusted with prisms of zircon (Hintze, 1922, p. 350). Apparently unabraded crystal fragments of monazite seem so unlikely to be recycled detrital grains that some workers have attributed the monazite to a source in granite, gneiss, and pegmatite exposed between Salôbro and Canavieiras, and in the Serra do Mar (Gorceix, 1884b). Hintze (1922, p. 350) summarized comments by Henri Gorceix—that is, if the crystal fragments of monazite came from granite instead of quartzite, then the monazite should be accompanied by heavy minerals common in the areas underlain by granite and gneiss. Chrysoberyl, spodumene, andalusite, and beryl are found in streams draining the granite and gneiss, but they are absent from the diamond placers at Salôbro. Thus, the heavy minerals indicate that the monazite came from the Lavras series. Inasmuch as the fragments of monazite have little or no detrital rounding, they may have been recrystallized when the Lavras series was metamorphosed, or have been etched and overgrown, as observed elsewhere by Derby (1900b, p. 218–219), when the Lavras series was weathered.

Vugs and druses lined with monazite, quartz, magnesite, and other minerals are exposed in magnesian marble at Catita Grande do Pirajá in the vicinity of Bom Jesús dos Meiras, Bahia (Uhlig, 1915). Pneumatolytic action of pegmatitic fluids on the marble was said by Leonardos (1937a, p. 16) to have formed the druses. Pegmatite dikes in the area consist of coarse-grained quartz and albite accompanied by beryl, topaz, spodumene, lithium mica, manganese garnet, tourmaline, xenotime, and monazite. Minerals in the druses include monazite, xenotime, magnesite, dolomite, rutile, sphene, tourmaline, hematite, and topaz. The monazite deposited in the druses is notable for its lack of thorium oxide. An average of two analyses made by Uhlig (1915, p. 41) showed that the monazite, specific gravity 5.162, contained only 0.05 percent of ThO_2:

[Analyst: Uhlig (1915)]

	Percent		Percent
Ce_2O_3	26.06	MgO	Trace
$(La, Nd, Pr)_2O_3$	39.92	MnO	Trace
Y_2O_3	2.78	H_2O	0.54
ThO_2	.05	Insoluble residue	.40
P_2O_5	29.34		
Fe_2O_3	Trace	Total	99.50
CaO	.41		

In its low amount of thorium oxide this monazite resembles monazite from low-temperature deposits, carbonatites, and marble elsewhere in the world.

Other localities to which the monazite-bearing pegmatite dikes and marble in the vicinity of Bom Jesús dos Meiras have been referred are the Serra das Eguas (Leonardos, 1937a, p. 9, 15), the southern spurs of the Serra do Espinhaço, and the upstream part of the Rio de Contas (Hintze, 1922, p. 352).

Thorium-rich monazite from Morro da Gloria, Itambé, Bahia has been analyzed to show the effects of progressive weathering on the composition of the monazite. The fairly stable water content may indicate that all the samples were only slightly weathered.

Chemical analyses, in percent, of monazite from Morro da Gloria

[Analyst: Peixoto (in Peixoto and Guimarães, 1953, p. 21)]

	Fresh	Slightly Weathered	Weathered
Ce_2O_3	32.60		
La_2O_3	28.77		
Y_2O_3	.98		
ThO_2	8.88	8.82	6.54
U_3O_8	.07	Trace	Trace
P_2O_5	25.43		
SiO_2	1.32		
Al_2O_3	.88	.89	1.19
Fe_2O_3	.48		
TiO_2	Trace		
CaO	.02		
MgO	.02		
MnO	.03		
PbO	.16	.16	.11
H_2O	.58	.27	.52
Total	100.22		

Red syenite from the Serra do Stauba, Bahia, contains accessory monazite (Derby, 1889, p. 113). Monazite occurs in gneiss at Estrada de Ferro de Nazareth in the vicinity of Ubaira (Areia), Bahia (Leonardos, 1937a, p. 15), and sandstones of Tertiary age along the coast of Bahia and Espírito Santo contain detrital monazite (Leonardos, 1937a, p. 9).

Detrital monazite, as has already been mentioned, is in the diamond placers in the tributaries to the Rio Pardo in the vicinity of the village of Salôbro. Specific localities mentioned by Gorceix (1884b; 1885a, p. 30), Oliveira (1902, p. 19–20), and Derby (1905, p. 165) include the Riacho Salôbrinho, the Rio Salôbro, the Córrego do Rico, the Córrego do Desengano, and the Córrego do São José. Detrital monazite is also found in the lower Rio Pardo at Jacarandá (Oliveira, F. de P., 1902, p. 19–20).

Diamond placers at Bandeira de Mello on the Rio Paraguaçu (Rio Paraguassu) are exceptionally rich in monazite compared to other diamond placers in Bahia (Hussak, 1899, p. 347–351; Hussak and Reitinger, 1903, p. 550–551; Hintze, 1922, p. 351; Leonardos, 1937a, p. 15). Accompanying the monazite and diamonds are detrital quartz, orthoclase, muscovite, biotite, chlorite, spinel, corundum, sillimanite, hercynite, xenotime, garnet, zircon, epidote, actinolite, chrysoberyl, diaspore, kyanite, rutile, ilmenite, hematite, magnetite, black tourmaline, and native gold. In addition to the usual quartz, the gravel in the stream contains some fine-grained garnetiferous biotite granite, amphibolite, chlorite gneiss and schist, sillimanite-bearing muscovite schist, and very rare fragments of coarse-grained sandstone. Pegmatitic granite is exposed in the valley of the Rio Paraguaçu not far upstream from the placers. Evidently the detrital minerals came from granitic rocks, gneiss, schist, and sandstone.

Monazite from the placers contains tiny leaves of a muscovitelike mineral as rare inclusions and has randomly arranged fluid inclusions. It is very rich in thorium oxide and has a specific gravity of 5.012. An average of five analyses of monazite from Bandeira de Mello gave the following results:

[Analyst: Reitinger (in Hussak and Reitinger, 1903, p. 559)]

	Percent		*Percent*
Ce_2O_3	32.14	Fe_2O_3	1.79
$(La, Pr)_2O_3$	10.61	ZrO_2	.60
Nd_2O_3	15.38	CaO	.20
ThO_2	10.05	H_2O	.92
P_2O_5	25.51		
SiO_2	2.63	Total	100.67
Al_2O_3	.84		

A later analysis of monazite from this locality, made by Guilherme Florence in 1908 (Furia, 1939, p. 31), showed only 3.76 percent of ThO_2. No evident reason for the difference between the analyses appears in the discription of the material analyzed. Indeed, it seems to the writer very unlikely that such dissimilar monazite could be collected from the same placer unless the monazite was virtually in place and the geologic provenance was wholly different for the two samples. Until more is known about the composition of monazite from Bandeira de Mello, the five analyses by Hussak and Reitinger must be accepted as the more convincing. The monazite from Bandeira de Mello thus seems to contain ten times as much thorium as monazite from the Riacho Varas in the São João da Chapada part of the Diamantina diamond district in Minas Gerais. Thorium-poor monazite at the Riacho Varas seems to be derived from sericite phyllite, whereas the thorium-rich monazite at Bandeira de Mello probably comes from garnetiferous biotite granite and pegmatitic granite.

PARAÍBA AND RIO GRANDE DO NORTE

Monazite is one of the 84 different minerals identified in the Borborema pegmatite district in northeastern Brazil (Rolff, 1946, p. 26–27), but no analyses of the monazite have been published. The district straddles the boundary between the States of Paraíba and Rio Grande do Norte (Moraes, 1956, fig. 3). It has been exploited as a source for beryl and for niobium and tantalum minerals, but no monazite has been produced. Accessory monazite occurs in pegmatite dikes in the vicinity of Sabugui (Santa Luiza) and Picuí, Paraíba, and at Capoeiras near Santa Cruz in Rio Grande do Norte (Johnston, 1945, p. 40). Detrital monazite has been found in eluvial and alluvial placers in the basins of the Rio Seridó and Rio Açu (Rio Assú) (Rolff, 1955) around São Rafael, Florâna, Acarí, and Currais Novos in the State of Rio Grande do Norte and at Picuí in Paraíba (Moraes, 1956, p. 137).

Murata, Dutra, Costa, and Branco (1958, p. 7) reported that monazite from plagioclase pegmatite at the Orquima mine in Município São Rafael in Rio Grande do Norte contains 8.4 percent of ThO_2. About 6 miles to the southwest of the mine, small crystals of monazite from a granite stock were found by Murata, Dutra, and coworkers to have 8.1 percent of ThO_2, and a large crystal of monazite from pegmatite at São Bento mine in Município São Bento, Rio Grande do Norte, was shown to contain 2.6 percent of ThO_2.

Analyses of monazite collected from a pegmatite dike at Santa Cruz, Rio Grande do Norte, by W. D. Johnston, Jr., are given.

Chemical analyses, in percent, of monazite from Santa Cruz

[Analyst: Marble (1949b, p. 71)]

	Fresh	Slightly weathered	Heavily weathered
RE_2O_3	68.40	44.14	40.45
ThO_2	.41	.95	1.05
P_2O_5	27.28	20.69	43.38
SiO_2	.35	----	----
R_2O_3	1.33	26.45	1.00
CaO	2.49	2.68	4.32
MgO	.03	----	----
H_2O+	.00	4.10	6.64
H_2O-	.00	.93	2.96
Total	100.29	99.94	99.80

In these analyses the percentage of thorium oxide increases as the degree of weathering increases. The analyses of fresh, slightly weathered, and weathered monazite shown from Morro da Gloria indicate a decrease in thorium oxide with increase in degree of weathering. Possibly something is wrong with one set of data.

GOIÁS AND MATO GROSSO

Monazite associated with thorite, orangite, fergusonite, gummite, and uraninite has been reported from the diamond-mining districts in the State of Goiás (Leonardos, 1937a, p. 9; Hintze, 1922, p. 350; Truchot, 1898, p. 146). Although the nature of the occurrence is not described, the mineral association indicates pegmatites as the source.

Fluvial deposits near Catalão, Goiás, are monazite bearing. A concentrate from this locality contained about 5.92 percent of ThO_2 but apparently had little more than 60 percent of monazite, to judge from an incomplete analysis given by Freise (1911, p. 258). Crystalline rocks are probably the source of the euhedral monazite reported from the diamond- and gold-bearing streams in the State of Mato Grosso (Hussak, 1891, p. 471–472; Hintze, 1922, p. 353).

BEACH PLACERS

Beach placer deposits of monazite are known but apparently are unexploited as far south in Brazil as the Ilha de São Sebastião on the coast of São Paulo (Engenharia, Mineraçao e Metalurgia, 1956). The mined coastal deposits extend northward intermittently from Rio de Janeiro through Espírito Santo to Canavieiras in Bahia (Brazilian Eng. and Mining Rev., 1905, p. 153; Miranda, 1943, 196–197; Lafer, 1950, p. 156; Leonardos, 1950, p. 137; Gillson, 1950, p. 686, Florêncio, 1952, p. 44; Strod, 1953, p. 123). The placers occur in modern beaches, old elevated beaches and bars, dunes, and in the banks and bars of streams emptying at the coast (Mertie, 1949, p. 632). The occurrence of the beach placers in certain places is related to the distribution of sandstone of Cretaceous and Tertiary age. Where the lower beds of the sandstone (Gillson, 1950, p. 686) crop out at the shore and are disintegrated by ocean waves, monazite and ilmenite are released to be sorted and deposited on the beaches. The Cretaceous and Tertiary sandstones are nowhere rich enough in monazite to be mined.

Monazite reworked from the coastal sandstone provides a more abundant supply for the present beaches than monazite discharged by streams. Beaches near bluffs supported by monazite-bearing sedimentary rocks are richer in monazite than beaches at the foot of granitic or gneissic cliffs or beaches at the mouths of streams. Old raised beaches inland from the coast and much modified by erosion may be rich sources for monazite. Natural concentrations of monazite at the surface along some storm beaches (marinhas) have occasionally reached 90 percent of the volume of the sand in the upper few inches of the beach, which permitted producers to skim the monazite from the beach and sell it without further treatment.

Monazite ordinarily makes up but a few percent to 7 or 8 percent of the total volume of the sand, and it has to be separated from the sand before it can be sold, but the variety of accessory minerals is less than in coastal deposits in the United States (Gillson, 1950, p. 692). Commercial monazite concentrates from Brazil contain 86 to 98 percent of monazite and average about 92 percent (Freyberg, 1934, p. 379). Between 1900 and 1947 Brazil exported 62,115 short tons of monazite concentrate of which 38,800 tons came from Espírito Santo and 23,315 tons came from Bahia and Rio de Janeiro (Brazilian Eng. and Mining Rev., 1905, p. 153; Gottschalk, 1915; Kithil, 1915, p. 13; Freyberg, 1934, p. 376–378; Erichsen, 1948, p. 76; Catriú, 1951; Mining Jour., 1942).

The sizes of the deposits are poorly discussed in the literature, though they are commonly stated to be individually smaller than the Indian placers. Evidently small, relatively rich deposits from which a few score tons to several hundred tons of monazite could be extracted annually attracted most attention until large monazite-bearing ilmenite placers were opened about 1927.

Reserves of monazite in the beach deposits, like the sizes of the individual placers, have received little comment in the literature. Kithil (1915, p. 19) admitted that estimates of the amount of monazite in the beach placers were difficult to make, but it seemed likely to him that the placers could yield a total of at least 15,000–20,000 tons of monazite. In the following 35 years 17,146 tons of monazite was produced from the beaches, and recent estimates considerably enlarged the reserves. Leonardos (1950, p. 137) estimated there was at least 100,000–150,000 tons of monazite along the coasts of Rio de Janerio, Espírito Santo, and Bahia. Two plants capable of processing 1,500–2,000 tons of monazite per year were being operated in 1953 at Vitória and São Paulo (Strod, 1953, p. 123).

RIO DE JANEIRO

Monazite placers along the coast of Rio de Janeiro are said to be small (Catriú, 1951, p. 289). Monazite is common in the beach sand at the city of Rio de Janeiro (Derby, 1889, p. 110), but some 75 miles along the coast to the east of that city, at the Praia Massanduba at Cabo Frio only small amounts of monazite occur in the coastal ilmenite placers (Gottschalk, 1915, p. 903). To the northeast, small beach placers are known at Barra de São João, Macaé, Retiro, Buena, Samambaia, and Ponta da Barrinha, the last being in the Município of São João da Barra near the mouth of the Rio Paraíba (Gottschalk, 1915, p. 903; Freyberg, 1934, p. 376; Abreu, 1937, p. 450; Miranda, 1943, p. 197). Sand bars and banks in the lower reaches and at the mouth of the Rio Paraíba are monazite bearing, and they may include some of the best placers in the State (Barbosa, 1909; Catriú, 1951, p. 290; New Zealand Mines Rec., 1905; Moraes, 1937, p. 67).

The average amount of thorium oxide in monazite from beach placers along the coast of the State of Rio de Janeiro has been reported as 5.87 percent by Leão (1939, p. 164), which probably refers to the analysis made by T. H. Lee in 1917 (Leonardos, 1937b, p. 559).

ESPÍRITO SANTO

Monazite was found in the coastal sand of the State of Espírito Santo in 1895 (Freise, 1910b, p. 471), and the first monazite mine was opened at Guarapari in 1898 (Borges, 1937, p. 66). An initial production of 660 short tons was exported in 1900 (Erichsen, 1948, p. 73; Frayha, 1947, p. 71–76). Shortly thereafter placers were opened elsewhere along the coast from Barra de Itabapoana in the south to São Mateus in the north (Mining Jour., 1903c). At least one placer, that in the vicinity of Ponta do Siri, was worked almost continuously until 1924. Loss of markets due to the production of monazite from India rather than depletion of the deposits brought closure. Mining of the beach placers in Espírito Santo was resumed in 1927 with monazite a byproduct of the recovery of ilmenite.

Reserves of monazite along the beaches of Espírito Santo have been collectively placed at more than 50,000 tons (Catriú, 1951, p. 290), and sums of the reserves for individual beach deposits in the State were estimated as about 15,000 short tons by Frayha (1947, p. 80–86) or about 150,000 short tons by Miranda (1943, p. 196–197).

The most numerous and most important ilmenite-monazite placers in Espírito Santo lie between Barra de Itabapoana and Guarapari (Moraes, 1937, p. 69; Erichsen, 1948, p. 77). With a few exceptions these deposits are elevated bars which form narrow ridges, a few hundred feet to 1.5 miles long covered by a thickness of 1–2 feet of low-grade or barren sand (Gillson, 1950, p. 689–690). Although the grade of the sand varies widely among the deposits, Gillson (1950, p. 690) estimated that the average for the elevated bars is 32 percent of heavy minerals of which about 55 percent is ilmenite, 5 percent is rutile, 25 percent is zircon, and 5+ percent is monazite; the balance consists mainly of tourmaline, staurolite, sillimanite, kyanite, and corundum. At Barra de Itabapoana, spinel is plentiful, but it is scarce or absent elsewhere. The deposit at Ponta do Siri (Bôa Vista de Siri, Siri, Siry, Ciri) is an isolated bar, some parts of which contain as much as 45 percent of monazite, but the total tonnage is not large (Gottschalk, 1915, p. 903; Freyberg, 1934, p. 377; Gillson, 1950, p. 690). About 2 miles north of Ponta do Siri at Maratayso Praia, the tenor drops to 7 percent of monazite, and the main monazite-bearing layer of sand is about 3,300 feet long, 20 feet wide, and 0.2 foot thick (Freyberg, 1934, p. 377). Placers at Maratayso Praia are said to be mined out (Hintze, 1922, p. 356).

Undescribed placers at Jacunem (Jucunem) have yielded monazite that contains 5.70 percent of ThO_2 (Leonardos, 1937b, p. 559; Leão, 1939, p. 163). Monazite from the coast of Espírito Santo has also been reported to have 6.75 percent, 6.00 percent (Leonardos, 1937b, p. 559), and 6.06 percent of ThO_2, but the exact location of the material analyzed was not specified (Imp. Inst. [London], 1914a, p. 60):

	Percent
Ce_2O_3 (group)	62.12
Y_2O_3 (group)	.80
ThO_2	6.06
P_2O_5	28.50
SiO_2	.75
Al_2O_3	.10
Fe_2O_3	.97
CaO	.21
Loss on ignition	.38

Large stream placers in the lower Rio Itabapoana are mentioned but not discussed by Catriú (1951, p. 289).

About 20 localities in the vicinity of Itapemirim, from Bôa Vista in the south to Meaípe in the north, have been mentioned as monazite deposits. They are mainly elevated bars of small size (Gillson, 1950, p. 690). Ilmenite and monazite placers at Bôa Vista were mined for monazite from 1909 to 1913 and in 1948 were estimated to contain 7,560 short tons of ilmenite and 127 short tons of monazite (Frayha, 1947, p. 83; Erichsen, 1948, p. 74–75, 83). The deposit at Meaípe was said to contain about 20,000 tons of heavy minerals, which included 55 percent of monazite (Miranda, 1943, p. 196); this deposit was at one time reputed to be the richest monazite placer in Brazil (Gottschalk, 1915, p. 904). In another estimate the reserves at Meaípe were given as 3,300 short tons of monazite (Freyberg, 1934, p. 377). Placers at Itapemirim, Pitas, Mangue, Sacco, Cacurucagem, Quartéis, Tiriricas, and Bôa Vista were said by Freyberg (1934, p. 377) to average 41 percent of monazite in the raw sand and to contain as much as 70.5 percent of monazite. This estimate of the relative abundance of monazite evidently refers to selected layers, because the estimate by Frayha of the reserves at Bôa Vista shows ilmenite 60 times more abundant than monazite.

Usually beach placers and elevated bars have monazite that varies only slightly from place to place in the amount of thorium oxide it contains, but the placers around Itapemirim seem to be an exception. They have been the sources of monazite that has a wide range in thorium oxide content. Analyses by T. H. Lee and L. C. Ferraz of monazite from Itapemirim, Itapicú, and Curú were reported to show 5.20, 7.09, and 11.50 percent of ThO_2 (Leonardos, 1937b, p. 559, Leão, 1939, p. 163), and monazite from Meaípe was said to contain 6.31 percent of ThO_2 (Miranda, 1943, p. 196).

In the vicinity of Anchieta, particularly about Parati, Imbiri, Pipa de Vinho, and the shore near the lake at Mãebá, various small placers, mainly elevated bars except Mãebá which is a modern beach placer, were mined for many years (Erichsen, 1948, p. 73–75; Gillson, 1950, p. 690). The deposit at Parati was thought by Frayha (1947, p. 87) to have good possibilities for monazite and was estimated by Erichsen (1948, p. 87) to have a reserve of 3,900 short tons of monazite. At Mãebá the reserves of monazite have been variously estimated as 1,500 short tons (Freyberg, 1934, p. 377) or at most 3,900 short tons (Frayha, 1947, p. 86; Erichsen, 1948, p. 75). The deposit was also said to contain 165,000 short tons of crude sand of unspecified tenor, from which concentrates containing 60 percent of monazite and 40 percent of ilmenite could be taken (Miranda, 1943, p. 196). Although the richest layers in these deposits may contain as much as 35 percent of monazite in the crude sand, they may be buried by barren overburden as much as 10 feet thick. Anchieta monazite as analyzed by L. C. Ferraz contained 5.20 percent of ThO_2 (Leonardos, 1937b, p. 559).

One of the main centers of mining between Itapemirim and Meaípe were placers at a locality known as Joana near Muquiçaba where ilmenite and monazite were produced between 1926 and 1941 (Frayha, 1947, p. 84; Erichsen, 1948, p. 75). No estimates of reserves in this deposit have been given.

A small placer in an elevated bar at Ubá (Ubú, Ubu), whose richest layers have 35 percent of monazite, was reported by Freyberg (1934, p. 377) to contain 310 short tons of monazite. The area was thought by Frayha (1947, p. 86) to be worth further exploration despite an earlier account that described the deposit as worked out (Hintze, 1922, p. 356).

Monazite from the placer at Mãebá contains an average of 6.5 percent of ThO_2 (Miranda, 1943, p. 196). Monazite from a placer between Mãebá and Meaípe had the following percentage of thorium oxide:

[Analyst: D. B. Borges (in Rocha, 1939, p. 19)]

	Percent
Ce_2O_3	30. 0
La_2O_3 (group)	30. 07
ThO_2	6. 31

About 4 miles north of Meaípe is the southernmost of the monazite-bearing beaches of the Guarapari region. Placers around Guarapari, including deposits at Praia do Vaz, Vila Velha, Rastinga, Canto do Riacho and Praia de Diogo, have been mined for both ilmenite and monazite since 1926 (Freyberg, 1934, p. 378; Miranda, 1943, p. 196; Frayha, 1947, p. 84; Erichsen, 1948, p. 75). One report implied that the placers around Guarapari contain only 0.4 percent of heavy minerals (Rocha, 1939, p. 18), however, this content probably refers to the average beach sand, because the local mining history shows that a much better grade of sand has been found, and Frayha (1947, p. 84) and Erichsen (1948, p. 85) noted that the placer at Canto do Riacho is one of the richest in Espírito Santo and has reserves estimated at 5,500–6,600 short tons of monazite. Miranda (1943, p. 196) seemingly indicated a reserve 15–20 times this great for the Guarapari region.

Monazite from Vila Velha was analyzed in 1933 by A. Girotto and reported (Leonardos, 1937b, p. 559) to have from 5.47 to 6.16 percent of ThO_2. The same reference reported the monazite from Guarapari to have 6.31 percent of ThO_2. Monazite from Praia de Diogo and Canto do Riacho contains 6.21 percent of ThO_2 (Miranda, 1943, p. 196).

The placer 15 miles north of Guarapari at Ponta da Fructa is mineralogically very different from other placers in southern Brazil. It is rich in zircon, garnet, and andalusite; the ilmenite is rich in TiO_2, and the monazite only appears in the lower layers of the placer (Erichsen, 1948, p. 81; Gillson, 1950, p. 690). The deposit is variously estimated to have reserves of 220 short tons of monazite (Freyberg, 1934, p. 378) or 2,200 short tons of monazite and 67,000 short tons of ilmenite (Frayha, 1947, p. 80–81; Erichsen, 1948, p. 81).

Beaches near the mouth of a stream at Piúma in the Município de Iconha are the sites of the Caju and Patrimônio deposits. Though they were at one time said to have been worked out as a source of monazite (Hintze, 1922, p. 356), they were explored for ilmenite in 1928–30 and in 1929 supplied 4,961 short tons of monazite-bearing ilmenite concentrate to Germany (Frayha, 1947, p. 87). The concentrate consisted of (Rocha, 1939, p. 19) the following minerals:

	Percent
Ilmenite	71. 61
Monazite	6. 00
Zircon	13. 00
Quartz	5. 97
Magnetite	. 22
Other minerals	3. 20
Total	100. 00

After 1929 various and conflicting estimates of the reserves of the Caju and Patrimônio deposits have been presented. Freyberg (1934, p. 377) was of the opinion that they contained 20 or 30 tons of monazite. The Caju deposit was estimated by Miranda (1943, p. 197) to contain 312,000 cubic yards of heavy sand consisting of 60–70 percent of ilmenite and 10–12 percent of monazite, the remaining percentage being dominated by zircon. An unnamed deposit at Piúma was said by

Miranda (1943, p. 197) to contain 55,000 short tons of crude sand having 5 percent of monazite. Monazite in the Piúma area contains 6.2 percent of ThO_2 (Rocha, 1939, p. 19).

Beach sands along the shore of the bay at Vitória contain monazite (Hintze, 1922, p. 356). Along the beach 10–12 miles north of Vitória the placer at Carapebús contains about 0.5 percent of monazite in the raw sand (Miranda, 1943, p. 197) and has reserves of monazite estimated to be 2,000 short tons (Frayha, 1947, p. 82; Erichsen, 1948, p. 82). The deposit at Carapebús was worked about 1910–12, and though past production is reputed to have been large, it has not been recorded (Gillson, 1950, p. 691; Frayha, 1947, p. 82).

The Serra, Capuba, and Jacaraípe deposits occur north of Vitória. Capuba and Jacaraípe are contiguous in a long, narrow bar (Gillson, 1950, p. 691). The deposit at Jacaraípe is said to contain 134 short tons of monazite and 9,750 short tons of ilmenite (Frayha, 1947, p. 82–83; Erichsen, 1948, p. 83).

A small placer occurs along the beach north of Vitória at Nova Almeida (Freyberg, 1934, p. 378). This placer is probably the same as the small placer referred to Bôa Vista de Nova Almeida by Gillson (1950, p. 691).

Twenty miles to the north of Nova Almeida particularly large monazite placers were said by Gottschalk (1915, p. 903) to have formed at the mouth of the Rio Doce at Regencia, but no particular information was given. Freyberg (1934, p. 378) mentioned that at Regencia 1–2 percent of monazite occurs with ilmenite and magnetite, but again the size of the deposit was not described. Gillson (1950, p. 691) observed many concentrations of titaniferous magnetite accompanied by garnet and some ilmenite in the delta of the Rio Doce, but monazite was not mentioned.

The most northerly of the monazite placers on the coast of Espírito Santo are between the mouth of the Rio São Mateus at São Mateus and the State boundary. These placers are of undetermined size and tenor but are thought to contain at least 550 tons of monazite (Freyberg, 1934, p. 378).

BAHIA

The coast of the State of Bahia, site of the first monazite mines in Brazil, is spotted with placers from the mouth of the Rio Mucuri (Rio Mucury) northward to Canavieiras. Locally the beach sands are yellow because of the abundant monazite (Gorceix, 1885a, p. 31; Leonardos, 1937a, p. 3), gray with brilliant black particles of magnetite and ilmenite, or red from fragments of garnet (Leão, 1939, p. 163). In places the sand is solidified but can be broken up with picks and hoes. An average of 10 analyses of monazite sand, presumably concentrates of different degrees of purity, from the coast of Bahia shows 3.33 percent of ThO_2 (Leão, 1939, p. 163).

In the vicinity of the town of Mucuri (Mucury), especially at the mouth of the Rio Mucuri, at Pôrto Alegre, the Riacho das Ostras, and Barra Nova, there are said to be notable monazite placers, but no details have been given. Monazite concentrates from Mucuri contain 1.5–5.0 percent of ThO_2 (Leonardos, 1937a, p. 14), and the monazite itself has 5–6 percent of ThO_2 (Leão, 1939, p. 163). According to Leonardos (1937a, p. 13–14), monazite placers extend continuously northward along the coast from Mucuri through Marobá (Viçosa) and Caravelas to Alcobaça. The tenor of the placers decreases northward to a low of 2.5 percent of monazite in the sand at Alcobaça (Leonardos, 1937a, p. 13–14). Values of the higher tenors in the south are not given by Leonardos, but locally they must be very high because at Caravelas there is enough monazite in the sand to give it a yellow cast (Gorceix, 1885a, p. 31). Besides monazite the placers around Caravelas contain zircon and sphene (Hintze, 1922, p. 351). Two old analyses of monazite concentrates from Caravelas made in 1885 by Gorceix (1885b, p. 34; Leonardos, 1937a, p. 13; Lisboa, 1950, p. 28) have high values for the rare earths; however, thorium was not determined independently but is included in the rare earths:

	Percent	
	A	*B*
Ce_2O_3	28.0	31.3
(La, Nd, Pr)$_2O_3$	35.8	39.9
P_2O_5	25.7	28.7
SiO_2	3.4	-------
ZrO_2	6.3	-------
CaO	1.1	-------
Total	100.3	99.9

A. Specific gravity, 5.1.

Monazite from nearby placers like those at Alcobaça contains the following percentage of thorium oxide (Johnstone, 1914, p. 58; Imp. Inst. [London], 1914a, p. 60):

	Percent		Percent
(Ce, La, Nd, Pr)$_2O_3$	61.40	Fe_2O_3	1.50
Y_2O_3	.70	CaO	.30
ThO_2	6.50	Loss on ignition	.64
P_2O_5	28.46		
SiO_2	.64	Total	100.22
Al_2O_3	.08		

Monazite from the placers at Mucuri contains 5–6 percent of ThO_2 according to analyses by L. C. Ferraz and 1.2–5.8 percent of ThO_2 as determined by Souza Carneiro (Leonardos, 1937b, p. 559). The latter determinations were probably made on impure concentrates.

The Prado area, mentioned earlier as the site of the first worked placers in Bahia (Smith, 1896, p. 372; Mining Jour., 1903b; Leonardos, 1937a, p. 3) includes deposits extending intermittently southward to Alcobaça and northward to Cumururatiba (Curumuchatiba), Caí (Foz do Cahy). Placers at Caí were mined in 1905 (Leonardos, 1937a, p. 12). Monazite-bearing beaches have been reported at Barreira, Itapará, Dois Irmãos, Córrego do Ouro (Rio do Ouro), Rio do Peixe, Ponta do Paixão, and Ponta da Barreira. The most important deposits are north of Prado at Comoxatiba, also known as Gordonia, where the placers along the storm beach are about 2 miles long, are 3–7 feet thick, and contain as much as 70 percent of monazite (Gillson, 1950, p. 692; Leonardos, 1937a, p. 13). The deposit was worked about 1903 by John Gordon. Accompanying the monazite are quartz, xenotime, spinel, garnet, tourmaline, anatase, pleonaste, staurolite, allanite, and thorite (Hintze, 1922, p. 351). Crude sand at Barreira and Ponta do Paixão consists of 50–90 percent of monazite, 6–43 percent of ilmenite, and 4–26 percent of zircon and quartz (Leonardos, 1937a, p. 12). No estimates of the sizes of the placers are given in the literature; however, it has been stated that erosion of sea cliffs by wave action in the vicinity of Prado annually frees 1,000 tons of sand having 70–75 percent of monazite (Gottschalk, 1915, p. 903; Freyberg, 1934, p. 378).

A wide range in the abundance of thorium oxide is reported for monazite from Prado. Concentrates of varying degrees of purity were analyzed by Herzfeld and Korn in 1900 and reported to contain from 1.50 to 3.50 percent of ThO_2 (Leonardos, 1937b, p. 558). Concentrates analyzed by Souza Carneiro contained 1.1–7.6 percent of ThO_2 (Leonardos, 1937b, p. 559). Monazite sand from Prado analyzed in 1900 at the Escola Minas Ouro Preto contained the following amount of thorium oxide (Moraes, Barbosa, and others, 1937, p. 132; Leonardos, 1937a, p. 13; Lisboa, 1950, p. 28):

	Percent
$(Ce, La, Nd, Pr)_2O_3$	62.70
Y_2O_3	3.00
ThO_2	3.50
P_2O_5	27.00
Al_2O_3	3.00
Fe_2O_3	2.50
Total	101.70

Monazite from Comoxatiba is variously reported to have 7.1–11.1 percent of ThO_2 (Leonardos, 1937a, p. 13), or 5.75 percent of ThO_2 (Leão, 1939, p. 163). Analyses by Souza Carneiro of monazite or monazite concentrates from Curumuxatiba disclose 1.1–11.1 percent of ThO_2 (in Leonardos, 1937b, p. 559).

Several small placers on the shore and at the mouths of streams north of Prado at Ponta Juacema (Enseada de Joacema) and Caraíva (Carahyba) have sand which contains almost 25–30 percent of monazite. Monazite from the placers at Caraíva has 5–5.5 percent of ThO_2 (Leonardos, 1937a, p. 12; Gottschalk, 1915, p. 904; Hintze, 1922, p. 351; Freyberg, 1934, p. 378).

The Porto Seguro placer district extends northward along the coast of Bahia from Trancoso to Santa Cruz. Beaches around the city of Trancoso are monazite bearing. In the vicinity of Porto Seguro, monazite occurs at Nossa Senhora da Ajuda (Ajuda), Rio da Villa, Toque-Toque, Rio São Francisco, and Porto Seguro. According to Leonardos (1937a, p. 12) the crude sand from Toque-Toque contains 55–65 percent of monazite, 20–21 percent of ilmenite, 15 percent of zircon, and 2 percent of quartz. Concentrates from the Porto Seguro district have 76–85 percent of monazite, 4–11 percent of ilmenite, and 12 percent of zircon and quartz. Monazite, possibly meaning monazite concentrate, from Toque-Toque has 1.4–7.3 percent of ThO_2, and the thorium oxide content was said (Leonardos, 1937a, p. 12) to exceed 6 or 7 percent in some analyses. Monazite concentrates from the mouth of the Rio Santa Cruz and the beaches at the city of Santa Cruz contain from 1.1 to 9.4 percent of ThO_2 (Leonardos, 1937a, p. 12).

Stream and beach deposits at the mouth of the Rio Jequitinhonha and at the mouth of the Rio Pardo at Canavieiras are monazite bearing. The placers at Canavieiras are the most northerly beach deposits with significant amounts of monazite that have been observed in Brazil.

PARAÍBA DO NORTE

An insignificant amount of monazite and rutile is associated with large beach and dune deposits of ilmenite and zircon at Cunhaú in Paraíba do Norte (Gillson, 1950, p. 692).

BRITISH GUIANA

Monazite in British Guiana was discovered in 1934 by Grantham in concentrates made from alluvium in streams draining a wide area of the southwestern part of the Kanuku Mountains (Grantham, 1937, p. 4). It was not found in large concentrations.

Reports of similar monazite-bearing concentrates from the same general area, between the Takatu and Rupununi Rivers, were given by Smith Bracewell in 1941 (Henderson, G., 1952, p. 125) and 1946 (Bracewell, 1946, p. 37). Monazite was tentatively identified with heavy minerals from red clay adjacent to biotite granite exposed 3.5 miles southwest of Wabwak Mountain in the Kanuku Mountains (Henderson, G., 1951, p. 34–35). Henderson also tentatively identified it in concentrates from the Marmiswau and Moriwau Rivers, tributaries to the Rupununi River near Wabwak Mountain, and in concentrates from Tutuwa and Wuratwau Creeks in the same area.

The plutonic rocks exposed in the Kanuku Mountains are granulite, sillimanite-garnet gneiss, and granite. Monazite is an accessory mineral in the sillimanite gneiss (Bracewell, 1947, geologic map; Matthews, P. F. P., 1953, p. 87–88).

The economic geology of the monazite placers in the Rupununi district was described by Dujardin (1955). He found the stream placers to have scant lateral extent, to be shallow, and to contain from a few hundred to several tens of thousands of cubic yards of gravel. The arithmetical average tenor of 15 samples of sand and gravel taken from the richest stream in the district, Wurriwia Creek, was 7.2 pounds of monazite per cubic yard. The samples ranged in tenor from 1.87 to 14.5 pounds of monazite per cubic yard. Silt and clay taken about a mile from the head of Wurriwia Creek contained 1.25 pounds of monazite per cubic yard. The area is remote and relatively undeveloped. No monazite had been produced in the Rupununi district or elsewhere in British Guiana as of 1958, though some mining companies were reported in 1956 to be investigating monazite deposits near the boundary between British Guiana and Brazil (Mining World, 1956).

CHILE

Monazite was mentioned by Falke (1936, p. 588) as a possible accessory mineral in fluvio-marine gold placers on the Isla de Chiloé, but none of the deposits was specifically said to have monazite. The placers are grouped into four areas on the west coast of the island. From south to north they are the Punta Catizo-Punta Checo area, the Rahue-Cucoa area, the vicinity of Pumillahue, and the Ancud-Chacoa area.

COLOMBIA

Detrital monazite is in gold placers along the Río Chico (Lleras Codazzi, 1916, p. 8; 1927, p. 94; Scheibe, 1931, p. 85) in Antioquia, Colombia. An early account of a concentrate from the Río Chico, published by Damour and Des Cloizeaux in 1857 (p. 445, 447), lists monazite as one of the heavy minerals. Other heavy minerals in the concentrate were gold, almandine, zircon, ilmenite, and sparse columbite, kyanite, wulfenite, and rutile. Damour and Des Cloizeaux were unable to find thorium in the monazite. Their analysis shows 29.10 percent of P_2O_5, 46.14 percent of Ce_2O_3, and 24.5 percent of La_2O_3.

The Río Chico drains the west margin of a mass of granodiorite and monzonite of probable Ordovician age that forms a batholith in crystalline schist (West, R. C., 1952, p. 20–29). Spread out over the batholith are deeply dissected fluvioglacial and fluvial sediments, possibly Pleistocene in age, which contain rich gold placers. The amount of monazite from the placers appears to be small (Davidson, 1953, p. 76). Although gold has been mined in the region since pre-Columbian times, no monazite has been produced.

An old mineralogical analysis of a concentrate from Zaragoza shows a trace of monazite, dominant ilmenite and zircon, and rare magnetite and chromite (Day and Richards, 1906b, p. 1222–1223):

	Pounds per short ton
Ilmenite	1, 484
Zircon	302
Quartz	192
Chromite	14
Magnetite	8
Monazite	Trace

FALKLAND ISLANDS

Beach placers containing monazite are known along the Falkland Islands, but they are of no economic value (Davidson, 1956a, p. 202).

FRENCH GUIANA

Monazite is a minor accessory mineral in pegmatite veins that occur as zones in, and grade into, granite exposed in the Courcibo River and Leblond Creek in the drainage basin of the Sinnamary River (Choubert, 1949, p. 102). The pegmatites are composed of microcline, plagioclase, biotite, and garnet.

Black sand from beaches in the vicinity of Cayenne consists of 75 percent of magnetite, 18 percent of ilmenite, 3 percent of zircon, and 4 percent of other minerals including monazite, rutile, sillimanite, garnet, staurolite, sphene, tourmaline, and topaz (Lebedeff, 1935, p. 406–407).

Monazite has not been mined in French Guiana.

PERU

Monazite was found in sand in the Río Pacasmayo in 1901 by Denegri (1906, p. 75) and was later shown by Freire Villafane (1950, p. 760) to occur along the coast from Pacasmayo to Sechura in beach sand and fine-grained dune sand. An analysis of a zircon-rich concentrate from the Río Pacasmayo showed 1.5 percent of ThO_2 and some cerium earths (Weckwarth, 1908, p. 18).

Monazite occurs as megascopic chocolate-brown crystals in pegmatite at the Tarcominas mine in the vicinity of Pampacolca, Castilla, Departmento de Arequipa. The pegmatite dikes are injected into gneiss, granite, and granodiorite. The gneiss is of sedimentary origin and is composed of muscovite, chlorite, epidote, garnet, plagioclase, and quartz. The granite and granodiorite are epidote bearing and are Mesozoic in age (Freire Villafane, 1948, p. 2–6). Accessory monazite is common in the pegmatite dikes in the region. Dominant minerals are kaolinized feldspar, quartz, muscovite, and biotite. Other minor accessory minerals are fergusonite, uraninite, apatite, zircon, magnetite, ilmenite, pyrite, chalcopyrite, and arsenopyrite (Freire Villafane, 1950, p. 758; 1951, maps).

Monazite has not been mined in Peru.

SURINAM

Monazite was recognized as early as 1908 (Middelberg, 1908, p. 6–7) among the heavy minerals accompanying gold in placers overlying schist and gneiss and in the savannahs of Surinam (Koloniaal Museum Haarlem Bull., 1909). It was again reported in 1917 (Indische Mercuur, 1917). Monazite is described by Ijzerman (1931, p. 40, 201–202) as a fairly common but minor accessory mineral in granites and unmetamorphosed sediments in Surinam.

Accessory monazite was observed by Ijzerman (1931, p. 289) in thin sections of the microcline-rich biotite granite at Cassipora on the lower Suriname River and in porphyritic biotite granite in the upper part of the basin of the Suriname River at Damanallé on the Pikien Rio, and at Goddo and Awa Fall on the Gran Rio (Ijzerman, 1931, p. 211–212). In the drainage basin of the Tapanahony River, porphyritic granite exposed on the Paloemeu River at the foot of a monadnock called Kassikassima, and nonporphyritic granite in the monadnock itself, contain monazite (Ijzerman, 1931, p. 216). Granite gneiss from Longoston on the Coppename River is monazite bearing (Ijzerman, 1931, p. 282).

The accessory monazite in these granites shows no distinct crystal shape, and rounded edges are common. Some grains of monazite have inclusions of zircon and apatite, but other accessory minerals common in the granites, like allanite, magnetite, ilmenite, pyrite, sphene, and primary epidote, are not included in the monazite. Ijzerman (1931, p. 202) interpreted these relations to mean that monazite crystallized as an early accessory mineral preceded only by zircon and apatite. Monazite does not occur in Surinam granites that have primary epidote.

Monazite was not identified by Ijzerman (1931, p. 362–373) in thin sections of sillimanite gneisses and schists from Surinam although it had been found by Middelberg (1908, p. 6–7) in placers overlying schist and gneiss.

Minor accessory monazite is associated with magnetite, ilmenite, leucoxene, rutile, muscovite, sillimanite, kyanite, andalusite, tourmaline, zircon, and garnet in continental sediments obtained from wells drilled about 25 miles south of Paramaribo (Ijzerman, 1931, p. 44), but it was not reported by Kiel (1955, p. 95) to be among the heavy minerals in the sedimentary rocks of the coastal plain of northeastern Surinam.

Monazite has not been mined in Surinam. The monazite in the gold placers was regarded as uneconomic in 1908 (Middelberg, 1908, p. 7).

URUGUAY

As early as 1889 detrital monazite had been observed on the Uruguyan banks of the Río de la Plata at Punta Caballos (Derby, 1889, p. 113; Johnstone, 1914, p. 58), but it was not until the 1950's that studies of the coastal placers were undertaken. Four recent papers discuss heavy minerals along the South Atlantic coast of Uruguay and indicate interest in their commercial possibilities as sources for ilmenite and monazite (Gõni, 1950, p. 102, 109; Ellis and Mercatini, 1955, p. 285; Jones, G. H., 1956, p. 91–92, 106; Bogert, 1959). The following account is drawn from these reports.

The heavy minerals are found in the Departamento de Canelones and occur intermittently along the coast eastward from Montevideo for 220 miles to the Brazilian frontier. Included among the heavy minerals are ilmenite, zircon, monazite, tourmaline, pyroxene, almandine, spessartite, pyrope, apatite, rutile, beryl, lapislazuli, brookite, epidote, kyanite, staurolite, hornblende, chromite, and garnierite. Originally these minerals occurred in the basement complex of Early Precambrian age. This basement complex consists of highly contorted garnetiferous biotite gneiss, migmatite of lower and middle subfacies of the amphibolite facies, granite, and pegmatite. They are exposed in the northern part of the Departamento de Canelones, but in the southern part they are covered by sedimentary rocks of Tertiary and Quarternary age which are as much as 200 feet thick. The sedimentary rocks have served as intermediate hosts for the heavy minerals, and where they have been eroded the heavy minerals have been further concentrated on the beaches.

The coast of Uruguay in this area is a flat uplifted shoreline composed of old barrier beaches and offshore bars. Behind these features are silted-up lagoons, swamps, and sand dunes. The dunes occupy sandy zones about a mile wide parallel to the shore.

The entire southern coast contains heavy minerals, but the richest concentrates are at Atlántida (Atlántida Beach) about 25 miles east of Montevideo. Other beaches with notable deposits of black sand are La Floresta, Soils, and Bella Vista. Lower concentrations but greater quantities of heavy minerals are found along the beaches at Costa Azul, San Luis, La Pedrera, Aguas Dulces, and La Coronilla.

The beaches are 100–150 feet wide between the high tide line and the first growth of vegetation. Samples from the upper 1.5 feet of sand on parts of the beach at Atlántida contained 12.3–76.2 percent of heavy minerals as reported by Bogert (1959) or 27.6–56.5 percent as reported by G. H. Jones (1956, p. 91). At Atlántida the zone of maximum concentration is 9,000 feet long, 70 feet wide, and 2 feet deep. The sand contains an average of 30 percent of heavy minerals consisting mainly of ilmenite (Bogert, 1959, p. 49):

	Percent of average concentrate
Ilmenite	82. 2
Zircon	5. 4
Monazite	3. 2
Magnetite	2. 5
Rutile	1. 0
Various silicates	2. 1
Residue	3. 6
Total	100. 0

Monazite from Atlántida contains 4.1 percent of ThO_2 (Bogert, 1959, p. 49).

Beaches at La Floresta and eastward at Solis and Bella Vista contain streaks of sand said to have respectively 52.4, 16.7, and 18.4 percent of heavy minerals. Locally zircon becomes nearly as abundant as ilmenite in the placers, but monazite seldom exceeds 5 percent of the concentrate.

VENEZUELA

Sparse grains of monazite occur in assemblages of heavy minerals separated from oil-bearing nearshore marine sandstone of Eocene age exposed east of Lake Maracaibo (Sutton, 1946, p. 1675–1676). The sandstone crops out on the Potreritos Ranch in the District of Bolivar, Zulia. In approximate order of abundance the heavy minerals in the sandstone are muscovite, tourmaline, zircon, leucoxene, chloritoid, garnet, magnetite, hematite, barite, ilmenite, rutile, pyrite, anatase, brookite, chlorite, monazite, and amphibole.

Monazite is unreported from the other sedimentary rocks of the Maracaibo Lowland (Depresión de Maracaibo) which range in age from Devonian to Recent. It probably originates as a rare accessory mineral in the metamorphic and igneous rocks of the Andes de Mérida and Sierra de Perijá which form the rim of the Maracaibo Lowland.

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