NATURAL OCCURRENCE OF THORIUM

GEOLOGY OF THORIUM DEPOSITS IN THE UNITED STATES

By William S. Twenhofel and Katharine L. Buck, U. S. Geological Survey

CONTENTS

ILLUSTRATIONS

ABSTRACT

Thorium is a lithophilic and oxyphilic element closely related geochemically to zirconium, uranium, and the rare-earth metals. All its compounds are quadrivalent, and most of them are highly refractory. Available data indicate that many acidic rocks become enriched in thorium during magmatic differentiation.

The principal thorium-bearing minerals are thorite, a thorium silicate, and monazite, a complex phosphate of the rare-earth metals and thorium. Other thorium-containing minerals—bastnaesite, thorogummite, thorianite, euxenite, and fluorapatite—are not now of economic importance as sources of thorium but are potential sources of byproduct thorium from certain localities.

Thorium minerals are most abundant in igneous rocks, pegmatites, veins, and placers. Placers are by far the most important commercial sources in the United States, although some veins may become important sources in the future. Nearly all the common and important thorium-bearing minerals resist natural decomposition and, hence, are not concentrated by secondary chemical processes. No important concentrations of thorium minerals, other than placers, have yet been found in sedimentary rocks.

Most thorium in vein deposits is associated with barite, calcite, and rare-earth minerals, such as bastnaesite, rather than with base and precious metals, although lead and zinc minerals are found in some deposits. Thorium- and rare-earth-bearing veins occur in California, Colorado, New Mexico, Montana, Wyoming, and Idaho.

Pegmatites rarely contain appreciable quantities of thorium minerals, and none of those known in the United States contains recoverable amounts of thorium.

Many igneous and metamorphic rocks, particularly biotite-rich granite and granite gneiss, contain monazite. At a few places in the United States, principally in North Carolina, South Carolina, Idaho, southern California, and New England, certain igneous and metamorphic rocks contain appreciable amounts of monazite. Some of these rocks have been the source for monazite-bearing placer deposits commonly occurring in the same terrane.

Pleistocene and Recent placer deposits of monazite-bearing sands and gravels are the source of most of the thorium produced in the United States. Important monazite-bearing placers are known in Idaho and Florida and in a belt extending from southern Virginia to Georgia; in these deposits the monazite has been derived from monazite-rich igneous and metamorphic terranes Other similar placer deposits containing monazite are known in California, Colorado, Oregon, and Washington.

Ancient placer deposits of monazite-bearing sands are known in the Goodrich quartzite of Precambrian age in the Upper Peninsula of Michigan and in the Deadwood formation of Cambrian age in Wyoming. None of these is a present-day source of thorium.

INTRODUCTION

Thorium has long been used, in small quantities relative to most other metals, for a variety of industrial purposes. It was first used industrially during the period 1890–1911 as an essential ingredient of gas mantles; the development and widespread use of the tungsten lamp since that time has largely supplanted the gas mantle and the consequent market for thorium. The manufacture of gas mantles is, however, still the principal use of thorium, although the amount consumed for such use is decreasing. Thorium is used also in tungsten lamp filaments, high-temperature refractories, polishing compounds, vacuum tubes, magnesium alloys, and as a catalyst.

Thorium has a potential use, which cannot yet be evaluated, as a source of fissionable material for the production of nuclear power. The future demands for thorium for the production of atomic energy will be determined by results of current experimentation.

Thorium, unlike uranium, does not have a natural fissionable isotope. However, natural $thorium^{232}$ when bombarded by slow neutrons produces $thorium^{233}$, which disintegrates through $protactinium^{233}$ to $uranium^{233}$, a fissionable isotope.

Much of the data contained in this report was assembled from unpublished reports by our colleagues of the U. S. Geological Survey, whose assistance is gratefully acknowledged.

GEOCHEMISTRY OF THORIUM

Thorium is not known to occur in elemental form in nature; it occurs, chiefly as a minor constituent, combined with oxygen and other elements to form oxides, silicates, phosphates, carbonates, and fluorides. All thorium compounds are quadrivalent, and most of them are highly refractory to weathering. Thorium is associated with the rare-earth metals, zirconium, hafnium, and uranium.

According to Rankama and Sahama (1950, p. 570), thorium "is conspicuously concentrated in the lithosphere, particularly in the uppermost parts of this geosphere * * *" and, hence, is strongly lithophilic.

Thorium is concentrated in felsic igneous rocks during magmatic differentiation, and granitic rocks contain 3–6 times as much thorium as do basaltic rocks (Rankama and Sahama, 1950, and Fleischer and Rabbitt, 1952). In this respect thorium is similar to hafnium, zirconium, the rare-earth metals, and uranium.

Data on the amount of thorium in different rocks are few because of the difficulties of measuring minute amounts of thorium. Published figures are of questionable validity because they were obtained by calculation from measurements of the thoron content and from measurements of radioactivity, assuming radioactive equilibrium. The available data indicate that the thorium content of most igneous rocks is not more than 25 parts per million (25×10^{-6} g per g), but some igneous rocks contain as much as several hundred parts per million.

Thorium and uranium seem to be closely associated in igneous rocks; the two elements are associated in the same minerals, and data indicate that the thorium-uranium ratio of various rocks throughout the world is approximately uniform. The average thorium-uranium ratio in igneous rocks is about 3 or 4 to 1, with the ratio ranging from 0 to 20.

The thorium-uranium ratio is much smaller in ocean waters than it is in igneous rocks. In fact, ocean waters contain more uranium than thorium, probably because thorium minerals are less soluble than are the uranium minerals.

The following data compiled by K. Rankama and T. G. Sahama (1950, p. 573) suggest the order of magnitude of thorium content in sedimentary rocks:

Rock	*Approximate Th content in grams per ton*
Rocks of arenaceous origin (Joly, 1910)	5. 4
Rocks of argillaceous origin (Joly, 1910)	12
Shales (Minami, 1935)	10. 1
Limestones (Evans and Goodman, 1941)	1. 1

Where not occurring in igneous rocks, thorium and uranium display marked dissimilarities. In ore deposits minable concentrations of both thorium and uranium are rarely found together.

A possible explanation of the fact that thorium and uranium are associated in the magmatic cycle but are not associated in the hydrothermal environment, is offered by E. S. Larsen, Jr., and George Phair (1954, p. 88–89). In the magmatic cycle both thorium and uranium crystallize along similar paths because of their similarities in ionic radius and similarly low concentrations. However, in the very late magmatic cycle E. S. Larsen, Jr., and George Phair postulate a change to oxidizing conditions whereby 4-valent uranium changes to 6-valent uranium, the latter being highly soluble in aqueous solutions, whereas the former is not. Thorium has only the 1 stable valence (4), and it is not rendered more soluble by the change to oxidizing conditions. Thus, because of the change in solubility of uranium and lack of change in solubility of thorium, the two elements naturally become separated under hydrothermal and later magmatic conditions.

THORIUM MINERALS

The most important thorium minerals are monazite, thorianite, thorite, and thorogummite. Other minerals that contain minor amounts of thorium are allanite, bastnaesite, xenotime, euxenite, fluorapatite, and zircon.

Monazite is the principal ore mineral of thorium in the United States and elsewhere. It is a complex phosphate of the rare-earth metals (principally cerium and lanthanum) and thorium. The thorium content normally ranges from a few percent to 10.6 percent, but probably can be as much as 26.4 percent thorium (Frondel and Fleischer, 1955, p. 185). Commercially recovered monazite contains from 55 to 65 percent of rare-earth oxides and thoria. Minable monazite deposits are found in the United States mostly in placers. Monazite also is an accessory mineral in many gneissic and granitic rocks and in calcareous metamorphic rocks and is a minor constituent of certain carbonate veins.

Thorianite (ThO_2) is isomorphous with uraninite (UO_2) and is a constituent of some placer deposits and a minor constituent of some igneous rocks. It is not now an ore mineral as its known occurrences are small and low grade.

Thorite ($ThSiO_4$) may contain from 25.2 to 62.7 percent thorium and as much as 10.1 percent uranium (Frondel and Fleischer, 1955, p. 190). It is typically a primary mineral of pegmatites and igneous rocks and certain hydrothermal veins recently discovered in the United States; it is considered to be a potential thorium ore mineral. Thorite and the variety uranothorite are the principal thorium-bearing minerals of certain placer deposits in Idaho.

Thorogummite (hydrothorite) is a hydrated silicate of thorium and uranium, containing 2.5–31.4 percent uranium and 18.2–50.8 percent thorium (Frondel and Fleischer, 1955, p. 191). It occurs in possibly significant amounts in veins or pegmatites in central Wisconsin and has been found elsewhere in the United States in very minor amounts associated with pegmatites and granitic rocks. Thorogummite probably is an important constituent of certain veins and mineralized shear zones in Colorado, Idaho, and California.

Allanite is a complex silicate containing as much as 3.2 percent thorium (Frondel and Fleischer, 1955, p. 197). Its characteristic occurrence is as an accessory mineral of plutonic igneous rocks and pegmatites; it also is found as a contact-metamorphic mineral associated with magnetite deposits. Allanite is not known in sufficient concentrations to be a source of thorium.

Bastnaesite is a fluocarbonate of the rare-earth metals, principally cerium and lanthanum, with less than 1 percent uranium and thorium (Frondel and Fleischer, 1955, p. 198). Though bastnaesite is not an ore mineral of thorium, it may become a source of byproduct thorium from the recovery of rare-earth metals. Most bastnaesite deposits are in contact metamorphic zones that are rich in rare earths, barium, carbon dioxide, and fluorine. Bastnaesite deposits have been mined at Mountain Pass, Calif., and in the Gallinas district, New Mexico (Anonymous, 1952, p. 108).

Xenotime, an yttrium phosphate, may contain as much as 2.2 percent thorium (Frondel and Fleischer, 1955, p. 203). It characteristically occurs in pegmatites and as a minor accessory mineral in granitic and gneissoid rocks. Xenotime is not known in sufficient concentrations to be a source of thorium but would contribute to the total obtainable from placers.

Euxenite is a complex oxide of thorium, rare earths, niobium, tantalum, calcium, and titanium, containing as much as 4.3 percent of thorium (Frondel and Fleischer, 1955, p. 179). It typically occurs as an accessory mineral in granitic rocks and in some of the placer deposits in Idaho is the principal thorium-bearing mineral present.

Fluorapatite is a fluorine-bearing apatite which in some localities contains rare-earth metals and thorium. In the Mineville district of New York (McKeown and Klemic, 1956), thorium-bearing fluorapatite is associated with magnetite ore, where it might be a byproduct source of thorium.

At the present time, the only ore mineral of thorium is monazite, which is principally an ore mineral of rare earths, but from which thorium is recovered as a coproduct. Thorite and thorogummite are of importance as potential sources of thorium from several districts in the Western United States.

THORIUM DEPOSITS

Thorium minerals in possible economic concentrations are found in granitic rocks, pegmatites, veins, and placers. The principal thorium deposits of the United States are shown on figure 181.

No known thorium deposits are comparable in grade and size to the well-known uranium deposits of pitchblende. Similarly, because thorium is relatively insoluble and occurs in highly refractory minerals, no known commercial thorium deposits of supergene origin are known.

VEIN DEPOSITS

In recent years, as interest in radioactive minerals has increased, vein deposits containing rare earths and thorium in significant amounts have been found in Colorado, Idaho, Montana, Wyoming, California, and New Mexico. Monazite, thorogummite, and particularly thorite, are the principal thorium-bearing minerals of these veins. These thorium-bearing vein deposits are characterized by the association of such gangue minerals as barite, carbonates, and iron oxides, with different amounts of other minerals. Most thorium-bearing veins occur in igneous and metamorphic terranes that have been intruded by alkalic

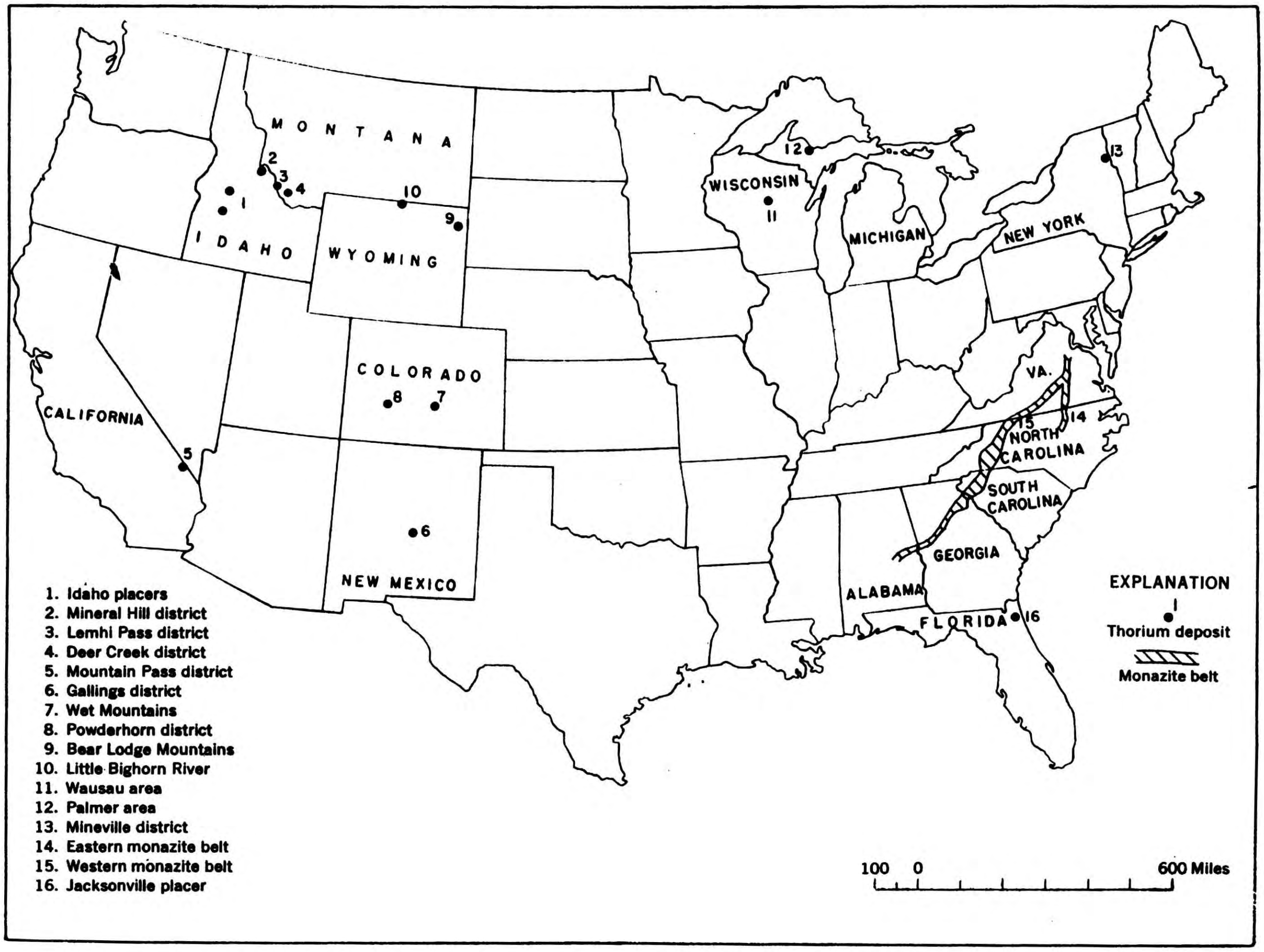

FIGURE 181.—Thorium deposits in the United States.

igneous rocks, believed to be genetically related to the veins.

POWDERHORN DISTRICT, GUNNISON COUNTY, COLO.

At least 33 deposits of thorium are known in the Powderhorn district of Colorado in an area 6 miles wide and 20 miles long. The deposits and the general geology are described by Olson and Wallace (1956). The area is underlain principally by Precambrian metamorphic and igneous rocks which have been intruded by pre-Jurassic alkalic dikes and composite stocks of irregular shape. The thorium deposits occur as thorite-bearing carbonate-rich veins and mineralized shear zones in or near the alkalic igneous rocks.

Selected high-grade samples of vein material contain as much as 4 percent thoria; the average thoria content of the veins is less than 1 percent. The veins are a few inches to 18 feet wide, and a few feet to more than 3,500 feet long. The vein material is composed principally of carbonate, quartz, and feldspar, with minor amounts of barite, pyrite, sphalerite, galena, hematite, goethite, apatite, thorite, xenotime, and many other minerals.

The thorium-bearing veins are characterized by the presence of titanium, barium, strontium, niobium, phosphorus, and the rare-earth metals, which also are present in greater than average amounts in the alkalic igneous rocks with which the veins are associated; these relationships suggest a genetic tie between the veins and the alkalic igneous rocks. The thorium minerals are accompanied by both oxidized and unoxidized iron-bearing minerals.

WET MOUNTAINS, COLO.

Thorium-bearing veins recently were discovered by the U. S. Geological Survey on the west flank of the Wet Mountains in Custer and Fremont Counties, Colo., (Christman and others, 1953). Over 350 thorium-bearing veins are known in the Wet Mountains area. Most of them are less than 5 feet wide and 100 to 1,000 feet long; a few are as much as 50 feet wide and 5,000 feet long. The country rocks of the area consist of a

Precambrian complex of interlayered paragneisses, migmatite, and granitic gneisses that have been transected by an abnormally radioactive albite syenite stock and by many northwest-trending dikes, veins, and fractures. The veins are composed principally of quartz, barite, and iron-bearing carbonates with an unidentified hydrated thoritelike mineral. Minor amounts of pyrite, chalcopyrite, tetrahedrite, galena, fluorite, and secondary copper minerals occur sparingly in the veins. The thorium mineral or minerals rarely are visible with the naked eye, because they are masked by ubiquitous iron oxides and hydroxides.

The thorium content is not uniform within the veins. Concentrations in the form of shoots, pockets, pods, and lenses are distributed erratically and discontinuously along the veins. Some parts of veins contain as much as 1.0 percent thoria, but large parts of the veins contain only 0.1 percent thoria. The thorium in the veins is thought to be genetically related to the albite syenite stock.

LEMHI PASS DISTRICT, IDAHO-MONTANA

In the Lemhi Pass district, Idaho-Montana (Sharp and Cavender, 1953), there are four types of veins, two of which contain thorium minerals. They are quartz-copper veins, some of which have been mined for copper-gold ore; quartz-hematite veins, none of which contains more than traces of thorium; quartz-barite-hematite-thorite veins, containing zones rich in barite and thorite (these constitute the largest percentage of thorium-bearing material in the district); and quartz-copper-thorite veins, some of which contain significant quantities of thorite. The country rock consists of sandstone, argillite, and quartzite of the Precambrain Belt series.

The quartz-copper-thorite veins range from a few inches to 10 feet in width and are as much as 500 feet long; the quartz-barite-hematite-thorite veins range from less than 1 foot to 50 feet in width and from 10 to more than 700 feet in length (Trites and Tooker, 1953, p. 191–205). A. F. Trites and E. W. Tooker (1953) have estimated some of the samples of vein material to contain as much as 6.6 percent calculated thoria, but most contain 0.1 to 1.2 percent thoria.

BEAR LODGE MOUNTAINS, CROOK COUNTY, WYO.

In the Bear Lodge Mountains of Wyoming, thorium and rare-earth minerals occur in abnormal amounts in iron-manganese veins in Tertiary igneous rocks (V. R. Wilmarth and D. H. Johnson, written communication, 1953).

The iron-manganese veins are composed principally of hematite, limonite, manganese oxides, orthoclase, and chalcedony; they are in intrusive monzonite and syenite porphyry of Tertiary age. The thorium and rare-earth minerals have not been identified. The thoria content of the veins ranges from 0.04 to 0.25 percent. Rare earths are abundant within some veins, isolated specimens containing as much as 12.68 percent of rare earths.

MOUNTAIN PASS DISTRICT, CALIF.

Rare earths-barium-thorium deposits occur in a belt 6 miles long in Precambrian carbonate rocks associated with potash-rich igneous rocks in the Mountain Pass district, San Bernardino County, Calif. The geology of the district is described in detail by Olson and others (1954). The deposits are of value principally as a source of rare-earth metals, which occur chiefly in the mineral bastnaesite, and as a source of byproduct barite. However, some deposits contain between 0.02 and 0.5 percent thoria, with local concentrations as rich as 6 percent thoria.

Thorium minerals occur as small amounts of monazite in a large body of carbonate rock and as thorite and thorogummite in veins. The principal minerals of the thorium-bearing veins are calcite and quartz, with lesser amounts of hematite and hydrated iron oxides, bastnaesite, barite, thorite, and other minerals. The association of hematite with thorite is a conspicuous feature of these veins.

Late andesitic dikes cut the country rock and the thorium- and rare-earth-bearing veins. Some of the richer deposits are near andesitic dikes, suggesting that aqueous emanations accompanying the dikes may have redistributed thorium already in the veins and concentrated it as thorite near the dikes (Olson and others, 1954, p. 62).

GALLINAS MOUNTAINS, N. MEX.

Bastnaesite occurs in the fluorspar deposits of the Gallinas Mountains, N. Mex. (Glass and Smalley, 1945), where the two minerals are associated with abundant barite and goethite (pseudomorphic after pyrite). The deposits occur along fissures and faults, and in breccias and shatter zones in clastic rocks of Permian age. Post-Permian intrusive quartz monzonites, rhyolites, and syenites form stocks, irregular bodies, and many small dikes and sills. The fluorite-bastnaesite deposits are believed to have been formed by hydrothermal solutions related to the igneous activity. Bastnaesite is commercially recovered from these deposits (Anonymous, 1952).

WAUSAU AREA, MARATHON COUNTY, WIS.

Near Wausau, Marathon County, Wis., thorogummite and thorium-bearing zircon are found in residual soil in an area of Precambrian syenites. Samples from the more radioactive concentrations in the soil contain 0.21–1.0 percent thorium, indicating possible thorium concentrations in the bedrock (R. C. Vickers, written communication, 1953).

MINEVILLE, N. Y.

The magnetite ore bodies of the Old Bed mine at Mineville, N. Y., contain fluorapatite unusually rich in thorium and rare earths (McKeown and Klemic, 1956). Gangue minerals consist of hornblende, augite, quartz, and feldspar.

The fluorapatite is disseminated and in thin seams in the magnetite. Samples of the fluorapatite contain 4.28–32.4 percent rare-earth oxides, 0.01–0.38 percent thoria, and 0.009–0.11 percent uranium.

The Old Bed mine is currently being mined for magnetite. Other nearby magnetite deposits are not known to contain thorium-bearing fluorapatite.

DEPOSITS IN IGNEOUS AND METAMORPHIC ROCKS

Many igneous and metamorphic rocks, particularly biotite-rich granites and granite gneisses, contain monazite. Such rocks, together with monazite-bearing pegmatites which commonly occur in the same terrane, are the source of placer monazite. None of the igneous rocks in the United States contain sufficient concentrations of monazite and thorium to be considered ore, and it is unlikely that igneous and related metamorphic rocks in the United States will become an ore of thorium in the near future. J. B. Mertie, Jr., (1953) estimated the granites and gneisses of the monazite belts of the Southeastern States to contain 0.00005–0.02 percent monazite.

Thorium- and monazite-bearing igneous and metamorphic rocks also are known in Idaho and Montana (Trites and Tooker, 1953), South Dakota (Vickers, 1954), and in San Bernardino County, Calif. (Olson and others, 1954; Moxham, 1952), but none of the rocks appear to be appreciably richer in thorium than similar rocks of the Southeastern States.

Many pegmatites contain thorium-bearing minerals, but none of the pegmatites known in the United States contain thorium minerals in economic concentrations. Two areas of thorium-bearing metamorphic rocks and pegmatites are known in Worcester County, Mass. (Johnson, 1951). At both of these localities the bedrock consists of alternating bands of feldspar gneiss and pegmatite, both of which contain thorium. The deposits are very large and probably average 0.03 percent thoria. Other pegmatites containing more-than-average quantities of thorium minerals are known in the Deer Creek district, Beaverhead County, Mont. (Trites and Tooker, 1953), and in the St. Peters dome area, El Paso County, Colo.

PLACER DEPOSITS

Monazite is the principal thorium-bearing mineral in placer deposits of the United States, although in some Idaho placer deposits thorite and euxenite are also important thorium-bearing minerals. Placer deposits of thorium-containing minerals are in central Idaho and in an area extending from southern Virginia to Florida. Associated minerals in thorium-bearing placers are the usual heavy minerals such as gold, zircon, magnetite, rutile, ilmenite, garnet, and others.

Stream placers were mined for monazite in the Piedmont province of North and South Carolina from 1887 to 1911 and from 1915 to 1917 (Mertie, 1953). Since 1911, monazite exported from Brazil and India has effectively competed with domestic monazite. Within the last few years, imports of monazite from foreign sources have been seriously curtailed (Mertie, 1953; Argall, 1954), and monazite now is recovered from placers in central Idaho and Florida.

SOUTHEASTERN STATES

The monazite in the placers of the Southeastern States is derived from the weathering and erosion of Precambrian igneous and metamorphic rocks of the Piedmont province. The monazite-bearing bedrocks are in two belts. Most of the rocks within these belts are not monazite-bearing; the belts delimit the areas within which monazite-bearing rocks are likely to be found. The western belt extends from east-central Virginia for 600 miles southwestward to Alabama; its width is 10–50 miles and averages 20 miles. The eastern belt extends from Fredericksburg, Va., southwestward for 200 miles into North Carolina; it averages about 5 miles in width.

J. B. Mertie, Jr., (1953) sampled 52 placer localities in the Southern States. The mean content of these samples is 8.4 pounds of monazite to the cubic yard, but at some localities the tenor was as much as 41.9 pounds of monazite to the cubic yard. The mean tenor of the monazite as determined by J. B. Mertie, Jr., (1953) from 53 samples is 5.67 percent thoria and 0.38 percent U_3O_8, with tenor ranging from 2.48 to 7.84 percent for thoria and from 0.18 to 0.98 for U_3O_8.

A large volume of sediments that contain heavy minerals, including monazite, derived from the Piedmont rocks has been deposited since Paleozoic time on the Coastal Plain of the Southeastern States. In some areas workable deposits of heavy minerals are found where ocean currents and streams have reworked these sediments. Placer deposits near Jacksonville and Starke, Fla., and at Hollow Creek, S. C. are being mined for heavy minerals. At the Jacksonville and Hollow Creek deposits, byproduct monazite is being recovered, but at Starke monazite is not being recovered

IDAHO

Thorium-bearing placer deposits scattered over a wide area in central Idaho contain monazite, thorite, and euxenite as the principal thorium-bearing minerals. The placers also contain a variety of other heavy minerals; notably zircon, magnetite, ilmenite, garnet, and gold.

At the present time only the monazite placers in the Cascade area, Valley County, are being mined; the euxenite-bearing placers of the Bear Valley area, Valley County, and the thorite-bearing placers of the Hailey area, Blaine County, are not being mined. It is of interest, perhaps, to note that euxenite and thorite seem to be mutually exclusive in the Idaho placers and that the placers being worked for monazite contain only traces of euxenite and thorite (Mackin and Schmidt, this volume).

Dredging and recovery of monazite from Idaho placers began in 1950 (Argall, 1954) shortly after foreign shipments of monazite to the United States were curtailed. Three dredges are now actively engaged in the production of monazite from the Idaho placer deposits (Mertie, 1953).

The thorium-bearing and other heavy minerals found in the Idaho placers were derived from the Idaho batholith of central Idaho. The placer deposits lie within and around the borders of the batholith. The Idaho batholith is a complex of granitic rock units ranging from diorite to granite; data indicate that the thorium-bearing minerals are contained in appreciable amounts only in the quartz monzonite phases of the batholith (Mackin and Schmidt, this volume).

The quartz monzonite parts of the Idaho batholith do not contain a uniform amount of thorium-bearing minerals; some parts contain only a trace, others may contain as much as half a pound of monazite per ton. So far as known, there is no systematic pattern to the distribution of thorium-bearing minerals in the quartz monzonite phases of the Idaho batholith.

Weathering of the quartz monzonite phases of the Idaho batholith and transportation by streams of the thorium-bearing and other heavy minerals have resulted in placer deposits being formed in many stream valleys and basins of central Idaho.

Alluvial fills, of sufficient size to be worked as placers, have formed in Pleistocene time in central Idaho by several factors that have reversed the normal processes of stream erosion. According to J. H. Mackin and D. L. Schmidt (this volume), "the principal causes of accumulation of the valley fills * * * are (1) Pleistocene block faulting; (2) late Pleistocene glacial derangement of drainage; and (3) blocking of drainage lines by Pleistocene basalt flows."

DEADWOOD FORMATION, BIG HORN MOUNTAINS, WYOMING

Monazite-bearing conglomerate is known in the basal part of the Deadwood formation of Cambrian age in Sheridan and Big Horn Counties, Wyo. The monazite occurs as detrital grains in the matrix of the basal conglomeratic facies of the formation. The monazite-bearing parts of the formation attain a thickness of as much as 8 feet and crop out over long distances along the valley of the Little Big Horn River.

Sufficient data are not available to estimate the thorium content of the monazite and the monazite content of the conglomerate. Estimates have been made ranging between 8 and 30 pounds of monazite per ton.

GOODRICH QUARTZITE, UPPER PENINSULA, MICHIGAN

Monazite-bearing conglomerate beds in the Precambrian Goodrich quartzite occur in the vicinity of Palmer, Mich. (R. C. Vickers, written communication, 1955). Here the Goodrich quartzite is about 850 feet thick and is composed of a coarse basal conglomerate which grades upward into interbedded quartzites and pebble conglomerates. There are at least two monazite-bearing zones, one near the base of the formation and the other about 400 feet stratigraphically above the base. The continuity and thickness of these two zones are not yet known.

The monazite occurs as detrital grains in the matrix of layers and lenses of pebble conglomerates 1 inch to 2 feet thick.

The conglomeratic character of the monazite-bearing parts of the Goodrich quartzite and the detrital monazite crystals clearly indicate that parts of the Goodrich quartzite are ancient placers which subsequently have been metamorphosed and preserved essentially as originally formed.

CALCAREOUS METAMORPHIC ROCKS

Deposits of monazite in marble and calcareous schist recently have been discovered in the Mineral Hill district in northern Lemhi County, Idaho (Abbott, 1954). The monazite forms porphyroblasts in phosphatic calcareous rocks of the Precambrian Belt series. The economic potential of these deposits is poorly known because they have been explored only to a limited extent.

SUMMARY

Current data permit several generalizations on the characteristics of thorium deposits in the United States:

1. Placer concentrations of monazite are derived directly from monazite-bearing igneous and metamorphic rocks or by the reworking of sediments originally derived from such rocks.

2. Vein deposits of thorium generally are associated with and genetically related to alkalic igneous rocks.

3. The principal thorium vein minerals are thorite, thorogummite (hydrothorite), and monazite.

4. Barite, carbonates, quartz, and especially iron oxides are commonly associated with thorium minerals in veins.

5. The principal thorium-bearing veins were found in the Western United States and are believed to be either Precambrian or Cretaceous and Tertiary in age.

REFERENCES CITED

Abbott, A. T., 1954, Monazite deposits in calcareous rocks, northern Lemhi County, Idaho: Idaho Bur. Mines and Geology, Pamph. 99, 24 p.

Argall, G. O., 1954, New dredging techniques recover Idaho monazite: Min. World, v. 16, no. 2, p. 26–30.

Christman, R. A., Heyman, A. M., Dellwig, L. F., and Gott, G. B., 1953, Thorium investigations, 1950–1952, Wet Mountains, Colo.: U. S. Geol. Survey Circ. 290, 40 p.

Fleischer, Michael, and Rabbitt, J. C., 1952, Geochemistry, *in* Annual review of nuclear science, Volume 1: Stanford, Calif., Annual Reviews, Inc., p. 465–478.

Frondel, J. W., and Fleischer, Michael, 1955, Glossary of uranium- and thorium-bearing minerals: U. S. Geol. Survey Bull. 1009–F, p. 169–209.

Glass, J. J., and Smalley, R. G., 1945, Bastnaesite: Am. Mineralogist, v. 30, p. 601–615.

Johnson, D. H., 1951, Reconnaissance of radioactive rocks of Massachusetts: U. S. Geol. Survey TEI–69, 18 p., issued by U. S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, Tenn.

Larsen, E. S., Jr., and Phair, George, 1954, The distribution of uranium and thorium in igneous rocks, *in* Faul, Henry [ed.], Nuclear geology: New York, John Wiley and Sons, p. 75–89.

McKeown, F. A., and Klemic, Harry, 1956, Rare-earth-bearing apatite at Mineville, Essex County, N. Y.: U. S. Geol. Survey Bull.–(in preparation).

Mertie, J. B., Jr., 1953, Monazite deposits of the Southeastern Atlantic States: U. S. Geol. Survey Circ. 237, 31 p.

Moxham, R. M., 1952, Airborne radioactivity surveys in the Mojave Desert region, Kern, Riverside, and San Bernardino Counties, Calif.: U. S. Geol. Survey TEM–360, 30 p., issued by U. S. Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, Tenn.

Olson, J. C., Shawe, D. R., Pray, L. S., and Sharp, W. N., 1954, Rare-earth mineral deposits of the Mountain Pass district, San Bernardino County, Calif.: U. S. Geol. Survey Prof. Paper 261, 75 p. [1955].

Olson, J. C., and Wallace, S. R., 1956, Thorium and rare-earth minerals in the Powderhorn district, Gunnison County, Colo.: U. S. Geol. Survey Bull. 1027–O.

Rankama, Kalervo, and Sahama, T. G., 1950, Geochemistry: Chicago, Ill., Univ. of Chicago Press, 912 p.

Sharp, W. N., and Cavender, W. S., 1953, Thorium deposits of the Lemhi Pass district, Lemhi County, Idaho, and Beaverhead County, Mont. [abs.]: Geol. Soc. America Bull., v. 64, p. 1555.

Trites, A. F., and Tooker, E. W., 1953, Uranium and thorium deposits in east-central Idaho and southwestern Montana: U. S. Geol. Survey Bull. 988–H, p. 184–208.

Vickers, R. C., 1954, Occurrences of radioactive minerals in the Bald Mountain gold-mining area, northern Black Hills, S. Dak.: U. S. Geol. Survey Circ. 351, 8 p.

Anonymous, 1952, Companies join with Heim to develop bastnaesite: Eng. and Min. Jour., v. 153, no. 1, p. 108.