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GEOLOGICAL SURVEY CIRCULAR 824

Thorium Resources of Selected Regions in the United States

Prepared on behalf of the
U.S. Department of Energy

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By M. H. Staatz, R. B. Hall, D. L. Macke,
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Thorium resources are reported on for the Pleistocene beach placers of northern Florida, stream placers of Idaho, veins and pipes in the Bokan Mountain district of Alaska, carbonatite dikes, and apatite-bearing iron deposits in the Mineville district of New York in the United States.

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CONTENTS

ILLUSTRATIONS

TABLES

Thorium Resources of Selected Regions in the United States

By Mortimer H. Staatz, Robert B. Hall, David L. Macke, Theodore J. Armbrustmacher, *and* Isabelle K. Brownfield

ABSTRACT

Thorium resources have been assessed in a previous report entitled "Principal thorium resources in the United States" (Staatz and others, 1979) for (1) veins in the larger districts, (2) massive carbonatites, (3) disseminated deposits, and (4) stream placers of North and South Carolina. This report is a sequel to that report and assesses thorium resources in (1) Florida beach placers, (2) Idaho stream placers, (3) veins and pipes in the Bokan Mountain district, Alaska, (4) carbonatite dikes, and (5) apatite-bearing iron deposits near Mineville, New York. Thorium resources for each of these categories are divided into reserves and probable potential resources. When data are available, each of these is then divided into the following cost categories: (1) the amount of ThO_2 producible at a cost of less than $15/lb (per pound), (2) the amount producible at a cost of between $15 and $30/lb, and (3) the amount producible at a cost of between $30 and $50/lb.

Beach placers of northern Florida have reserves of 16,200 short tons of ThO_2 and probable potential resources of 5,120 tons of ThO_2. These deposits are heavy-mineral placers that are mined for a variety of minerals—principally titanium minerals and zircon. The thorium-bearing mineral in these placers, monazite, makes up only a minor part of the heavy minerals. Therefore, production of ThO_2 from these placers is dependent on the markets for other heavy minerals. Assuming the market for other heavy minerals to be the same as in 1978, then 98 percent of the ThO_2 could be produced for less than $15/lb. If, however, no other coproducts were produced, then the cost of producing ThO_2 would be greater than $50/lb.

Stream placers containing thorium are found along many streams that drain the Idaho batholith, but most are too small to add significantly to the thorium resources. The resources of the five largest districts, each of which consists of at least several individual placers, have been tabulated. These districts are (1) Long Valley, (2) Bear Valley, (3) Burgdorf-Warren area, (4) Boise Basin, and (5) Elk City-Newsome area. These five areas have reserves of 10,100 short tons of ThO_2 and probable potential resources of 10,300 tons. Long Valley contains about half the reserves—5,680 tons of ThO_2—and all the probable potential resources. Monazite is the most important heavy mineral in all except the Bear Valley deposit. Here euxenite, although not quite as abundant as monazite, is a more important mineral, because it contains approximately 14.5 percent U_3O_8 in addition to 5 percent ThO_2. Reserves in this placer amount to 1,605 short tons of ThO_2 and 1,475 tons of U_3O_8. Eighty-two percent of the reserves and all of the probable potential resources can be produced at less than $30/lb of ThO_2. The lower cost reserves are concentrated in the Long and Bear Valley areas. Here 64 percent of the ThO_2 can be produced for less than $15/lb and another 29 percent of the ThO_2 at between $15 and $30/lb.

Sixteen veins and pipelike bodies are evaluated in the Bokan Mountain area of southeastern Alaska. The district contains other deposits that are too poorly exposed to make meaningful resource estimates. Reserves estimated in this district are 1,440 short tons of ThO_2; probable potential resources amount to 2,320 tons of ThO_2. About 99 percent of these resources are in deposits whose grade is at least 0.2 percent ThO_2. In addition, these deposits contain reserves of 420 tons of U_3O_8 and probable potential resources of 820 tons of U_3O_8. Eighty-two percent of the reserves and probable potential resources can be produced at less than $15/lb. The average grade of this ore is 0.54 percent ThO_2 and 0.15 percent U_3O_8.

Some carbonatite dikes, although generally not as high grade as the veins, contain resources of thorium. Carbonatite dikes in the following six districts were investigated: (1) Wet Mountains, Colo.; (2) Powderhorn district, Colorado; (3) Mountain Pass area, California; (4) Bearpaw Mountains, Mont.; (5) Ravalli County, Mont., and Lemhi County, Idaho; and (6) Magnet Cove-Potash Sulfur Springs, Ark. Sufficient resources are present in the first three districts to merit resource calculations. These three districts have reserves of 978 tons of ThO_2 and probable potential resources of 5,480 tons. The Powderhorn district contains 77 percent of these resources. About one-third of the total reserves and probable potential resources could be produced at a cost of less than $15/lb. Another half of the reserves and probable potential resources could be produced at a cost of between $15 and $30/lb.

Thorium, together with rare earths and a little uranium, occurs in apatite that makes up approximately 8 percent of high-phosphorus iron ore tailings from the Mineville, N.Y. area. Iron mines have been operated in this district for over 150 years, and tailings piles contain millions of tons of material. Conservative estimates indicate that the dumps have reserves of 1,360 short tons of ThO_2, which could probably be produced at a cost of less than $30/lb.

INTRODUCTION

The U.S. Geological Survey, under a contract with the U.S. Department of Energy, began compiling data on thorium resources in the United States in May 1977. The Department of Energy wished to obtain data on most of the better known deposits within a year. A report covering thorium in many of the vein deposits, disseminated deposits, massive carbonatites, and stream placers in North and South Carolina was submitted to the Department of Energy a year later. This report, entitled "Principal thorium resources in the United States" was subsequently published (Staatz and others, 1979). The data on resources that were used in this early report were mainly a byproduct of regional studies of thorium districts made by the U.S. Geological Survey over the past 20 years.

The present report is a continuation of this assessment of thorium resources in the United States. It involves resources of districts that have been studied or compiled over the past 2 years. Specifically it covers (1) beach placers of northern Florida, (2) stream placers of Idaho, (3) veins and pipes in the Bokan Mountain area of southeastern Alaska, (4) carbonatite dikes in Western United States, and (5) iron deposits in the Mineville area of New York. This progress report does not cover any of the deposits described in the previous report (Staatz and others, 1979), and it covers only part of the other thorium deposits not previously covered. The material covered has been limited by data available in the literature and time necessary to obtain new data in the field.

Research on and compilation of various parts of this report were done by the following people: Staatz wrote the sections on Bokan Mountain, Alaska, and Mineville, N.Y. either from his notes or from the literature. Armbrustmacher is responsible for the section on carbonatite dikes. Macke put together the section on beach placers of northern Florida. Hall collected the data on the Idaho placers. Brownfield calculated the costs of producing ore from various properties.

Much data on geologic background, geologic literature, past production, and size, and extent of the deposits were obtained in conversations with people who have worked in these various areas. We are indebted to many people for their shared knowledge and their hospitality while in the field. Among those who have aided us in this study are Thomas E. Garnar, Jr., John W. Sweeney, Allan Popp, J. K. Thomas, James L. Hetherington, E. C. Pirkle, and C. W. Hendry, Jr., in the Florida area; Richard B. Porter, J. P. Jennet, Carleton N. Savage, and Miles Young in Idaho; Allan Bird, Robert L. and Irene Dotson, and Kelly Adams at Bokan Mountain, Alaska; Drew F. Holbrook and Don R. Owens on Arkansas carbonatites; and Harry Klemic in the Mineville, N.Y. area.

The present resource study on thorium was also supported by the U.S. Department of Energy. The terms "reserves" and "probable potential resources" used in this report are those of the Department of Energy. These terms have been adopted so that the thorium resources can be compared more directly with uranium resources. This comparison is important, as both metals compete as fuel sources for nuclear reactors. "Reserves," as used by the Department of Energy, is equivalent, for the most part, to the terms "measured and indicated reserves," as used by the U.S. Geological Survey and the U.S. Bureau of Mines. "Probable potential resources" is, likewise, in part equivalent to "inferred reserves" and some "hypothetical resources." Resource figures for each deposit are reported several ways. First, the reserves and the probable potential resources of each district are given. Then, these figures are divided into cost categories—the amount of ThO_2 that each could produce for less than $15/lb (per pound), for $15 to $30/lb, and for $30 to $50/lb. These cost boundaries were chosen so that they would be directly comparable to those used by the Department of Energy in reporting uranium resources.

SUMMARY

Resources of five types of thorium-bearing deposits are discussed in this paper. These resources are confined to those of a particular type in a specific area. For example, the section

TABLE 1.—*ThO_2 reserves and probable potential resources, in short tons, from selected districts in the United States*

Type of deposits	District or area	Total reserves	Total probable potential resources	Total producible at less than $15/lb		Total producible at between $15 and $30/lb		Total producible at between $30 and $50/lb	
				Reserves	Probable potential resources	Reserves	Probable potential resources	Reserves	Probable potential resources
Beach...... placers.	Northern... Florida.	16,200	5,120	15,800	5,120	190	0	168	0
Stream..... placer.	Idaho......	10,100	10,300	4,640	6,560	3,800	3,760	797	0
Veins and.. pipes.	Bokan Mountain, Alaska.	1,440	2,320	1,180	1,890	0	0	80	290
Carbonatite dikes.	United..... States.	978	5,480	332	1,920	482	2,780	0	0
Iron....... deposits.	Mineville, N.Y.	1,360	0	0	0	1,360	0	0	0
Total.................		30,078	23,220	21,952	15,490	5,632	6,540	1,045	290

on stream placers is confined to those in Idaho. Resources of stream placers in North and South Carolina have been previously reported (Staatz and others, 1979). The five types of deposits studied in this report have 30,100 tons of reserves and 23,200 tons of probable potential resources, for a total of 53,300 tons of ThO_2.

The largest amount of reserves (16,200 tons of ThO_2) occurs in the beach sands of Florida. These deposits are quite large, but the ThO_2 content is low. Such deposits in northern Florida and adjacent Georgia are mined principally for their titanium content. These deposits have been the only domestic source of thorium in the United States since at least 1960. The ThO_2 in these deposits is all byproduct and depends on the recovery of other heavy minerals. If these deposits were mined only for ThO_2, the cost per pound would exceed $50. The presence of a sizable market for ThO_2 would help put several marginal deposits into operation. Table 1 shows the cost of obtaining thorium from beach placers if they were operated under economic conditions existing in 1978.

The resources of the Idaho stream placers (reserves plus probable potential resources) are almost as large as those of the Florida placers. The stream placers differ from the beach placers in that monazite is the principal heavy mineral and, with the exception of one placer area, other heavy minerals have little effect on the cost of production. The one exception is Bear Valley, which also has euxenite. In this placer almost as much U_3O_8 would be recovered as ThO_2.

Total reserves and probable potential resources of ThO_2 of the different types of deposits, as well as those resources producible within various cost ranges are given in Table 1.

FLORIDA BEACH PLACERS

Monazite-bearing beach placers in northern Florida and southern Georgia have been the only source of domestic thorium since at least 1960. Monazite, however, makes up only a small part of the total heavy minerals, and these deposits are mined principally for their titanium, which is used in the pigment industry. Other mineral byproducts that have been marketed from some of the deposits include zircon, kyanite, sillimanite, staurolite, and garnet. Monazite is present in very small quantities in many surficial sands in Florida (Carpenter and others, 1953, p. 789). It is most commonly concentrated in modern or raised beaches. During 1978 monazite was produced from two of the three operating heavy-mineral deposits in Florida: Titanium Enterprises at Green Cove Springs and Humphrey Mining Corporation at Boulogne recovered monazite as a byproduct. At the third deposit, E. I. du Pont de Nemours and Company's Trail Ridge deposit, only trace amounts of monazite are present.

Heavy minerals have been mined at six places in Florida, and the details are summarized below. The first mining was started in 1916 along a modern beach near Mineral City by Buckman and Pitchard, Inc. (Martens, 1928, p. 125). This town, which is now known as Ponte Vedra, lies due east of Jacksonville. Ilmenite was the chief product, although some monazite was apparently recovered in 1916 or 1917 (Liddell, 1917, p. 153). The property was acquired in 1922 by National Lead Company, which is reported to have produced 1 short ton of monazite in 1925 (Santmyers, 1930, p. 11). Mining ceased in 1929.

In 1940 the Riz Mineral Co. began mining ilmenite, zircon, and rutile from monazite-bearing sands along the modern beach near Melbourne in the central part of Florida's eastern coast. A little later the company began to recover monazite, as well as ilmenite, rutile, and zircon, from dune sand near Vero Beach about 30 miles to the south (Overstreet, 1967, p. 125). This operation was more or less continuous until 1946 and then intermittent until 1948, when the company was reorganized under the name Florida Ore Processing Co., Inc., with a mineral separation plant at Palm Bay. This company ceased mining in early 1955 but continued processing concentrates dredged by the Florida Minerals Co. until October 19, 1955, when the plant burned. A new plant built near Winter Beach began operations in February 1956 (Overstreet, 1967, p. 125). The Winter Beach plant ceased operations in 1965 (Stamper, 1966, p. 940).

In 1943 the Rutile Mining Co., a subsidiary of National Lead Co., began recovering ilmenite and rutile from monazite-bearing sand just east of Jacksonville. This sand was from older Pleistocene and Pliocene beaches approximately 15 miles west of the Atlantic Coast. This plant recovered mainly ilmenite, rutile, and zircon, although a small amount of monazite was reported to have been produced annually (Overstreet 1967, p. 125; Gunter, 1955, p. 54). Production ceased in 1968 and the plant was dismantled.

In 1949 E. I. du Pont de Nemours and Company started producing heavy minerals from the large Trail Ridge orebody southwest of Jacksonville. This orebody, which has been traced for about 18 miles, lies along one of the higher beach lines in the state. Production started with the opening of a plant southeast of Starke. It was expanded with the opening of a second plant on another part of this deposit at Highland near Lawtey in 1955, (Overstreet, 1967, p. 125). Titanium minerals are the main product, but zircon, staurolite, kyanite, and sillimanite are also marketed (Garnar, 1972). Monazite is scarce in this sand body.

In 1972 Titanium Enterprises, Inc., a joint venture of Union Camp Corporation and American Cyanamid Co., began mining on a Pleistocene beach placer south of Jacksonville and west of the St. Johns River. The sand mined had an average of 3 percent heavy minerals; monazite made up approximately 0.3 percent of the heavy minerals. This plant had a designed capacity of 1,200 tons of sand per hour. Minerals recovered included ilmenite, leucoxene, rutile, zircon, and monazite. Mining ceased in June 1978 and the property was put up for sale.

In 1974 Humphrey Minerals, presently a subsidiary of Buttes Gas and Oil Co., began mining a heavy-mineral deposit near Boulogne in northernmost Florida. This deposit is part of a Pleistocene shoreline that extends northward across the St. Marys River into Georgia. Previously, a heavy-mineral deposit along the same shoreline was mined near Folkston, Ga., by the same company. The Boulogne orebody underlies an area of about 1,000 acres and was mined to an average depth of about 15 feet. This orebody has about 4 percent heavy minerals, of which monazite makes up 0.3 to 0.4 percent. Titanium minerals were the principal product here; byproduct zircon and monazite were also recovered. Active mining ceased late in 1978.

The present report does not include all of Florida, but is confined to the Pleistocene and Pliocene placers of northeastern Florida. As noted previously, some of the early heavy-mineral operations occurred along the modern beaches on the east coast of Florida. Other resources occur along these beaches and on adjacent offshore islands. Since the late 1960's environmental restraints have made the mining here more costly. Also, the real estate values of beach-front property have skyrocketed. Even in the past the older inland beach deposits were preferred to deposits on modern beaches because the inland deposits are larger, have more uniform distribution of heavy minerals, and are not as vulnerable to severe storms (Overstreet, 1967, p. 125). Thus, it appears unlikely, despite any resources present, that any placers along the seashore will be mined in the future in Florida. Pleistocene and Pliocene beach placers, however, which occur inland along old shorelines, were available in 1978 for development. These deposits are in general parallel to the present east coast and as much as 50 miles inland. Most are concentrated in the northeastern part of the State. Hence, the present study is confined to an area from the east coast westward to about long. 81° W., and from the Georgia border southward to the Green Cove deposit at about lat. 30° N.

Pleistocene and Pliocene beach placers are heavy-mineral concentrations in parts of relic shorelines, which occur in the outer coastal plain from Maryland to Florida. Relic shorelines are found at elevations ranging from about 10 to 110 feet above sea level. The older, higher shorelines are farther inland, and the younger are towards the present coast. Shoreline scarps were recognized in the Atlantic coastal plain more than a century ago by Lyell (1845). These shorelines, which were called "marine terraces," were described by Shattuck (1906) in Maryland, Clark and Miller (1912) in North Carolina, Stephensen (1912) in North Carolina, and Veatch and Stephensen (1911) in Georgia. Relic shorelines have been mapped in Florida by Parker and Cooke (1944), MacNeil (1949), Vernon (1951), Doering (1960), Alt and Brooks (1965) and Winkler and Howard (1976, p. 124-125). Cooke (1931, 1932) attempted the first correlation of these so-called "marine terraces" between States based on the elevation of their tops. He developed a sequence of seven named terraces, whose elevations ranged from 25 to 270 feet. MacNeil (1949) limited the number of separate terraces to four. Vernon (1951) and Alt and Brooks (1965) described four and five terrace levels, respectively. Significant differences also occur between the terrace elevations and nomenclature proposed by these various investigators. These studies relied on an assumption of tectonic stability and absolute elevation of shoreline features (MacNeil, 1949, p. 97; Doering, 1960, p. 185).

A better understanding of these relic shorelines has come from recognizing that they closely resemble barrier-islands formed along modern coasts, rather than marine terraces, and that the coastal plain has been warped during Pleistocene time and the old strand lines may therefore vary considerably in elevation. Probably the best correlation of ancient shorelines is by Winkler and Howard (1976), who used basin and ridge patterns to trace Pleistocene coastal geomorphology. Forms used were (1) seaward-facing scarps, (2) beach and dune ridges, and (3) ridge and swale lineations that were commonly preserved as trellis drainage or alined karst features to outline the extent and form of the relic seashores. They discarded age correlations that used standard elevations and based their age correlations on the pattern of net progradation, as seen in plan view, and the state of preservation of relic depositional surfaces. Using this system Winkler and Howard (1976) have divided relic shorelines on the Atlantic coastal plain from Florida north to Cape Fear River in North Carolina into three major and two minor sequences. Our work on Landsat satellite photography as well as on topographic maps supports this conclusion. Winkler and Howard (1976, p. 124–126) named their three major divisions from west to east the Trail Ridge, Effingham, and Chatham sequences.

Each of these sequences consists of a major transgressive event marking the highest level of the sea stand, followed by a regressive sequence of shoreline features that is interrupted by minor fluctuations and pauses in sea-level retreat. The Trail Ridge sequence has been assigned an age of 3–5 m.y., and the Effingham sequence 1.0–1.7 m.y.; the Chatham sequence has been dated near Cape Canaveral at approximately 110,000 years old (Berggren and Van Couvering, 1974; Osmond and others, 1970).

All three sequences are regressive sequences, and their maximum elevation above sea level decreases from the Trail Ridge to the Chatham sequence. The maximum elevation of the Trail Ridge sequence is about 165 feet, the Effingham sequence about 95 feet, and the Chatham sequence about 50 feet.

The sands in the Trail Ridge sequence are somewhat coarser than those in the other sequences, and its heavy minerals do not include monazite, garnet, and epidote (Garnar, 1972, p. 17). As this sequence does not have any thorium resources, it will not be discussed further.

In Florida both the Effingham and the Chatham sequences consist of a series of shorelines that are parallel to and resemble the present coastline. Monazite-bearing heavy-mineral deposits have been found in both sequences. The Boulogne and Green Cove Springs heavy-mineral orebodies are related to relic shorelines in the Effingham sequence. The orebody mined at Jacksonville is within the Chatham sequence. Other unmined heavy-mineral orebodies are found within the Chatham sequence.

Monazite and other heavy minerals found in the relic shorelines were originally derived from the crystalline rocks of the Piedmont province (Mertie, 1953, p. 13). These heavy minerals were carried seaward along various rivers and then southward by offshore currents. Some of these heavy minerals were incorporated into Tertiary or Quaternary rocks along the coastal plain and later released by erosion of these rocks. Thus, the heavy minerals may have gone through several sedimentary cycles before they were finally deposited in the beach bars, where they are found today. Variations in the mineral content of beach placers are due not only to differences in the original rocks from which they were derived, but also to changes that took place during various sedimentary cycles.

The concentration of heavy minerals in beach placers is a multistage process. It begins as the heavy minerals are transported by longshore drift. Particles are segregated by specific gravity and particle size and shape in the uppermost littoral zone during wave action. Wind action following the initial segregation acts to disperse the heavy minerals that are concentrated in the littoral zone. The result is to form coast-parallel dunes that have a heavy-mineral content intermediate between that of the littoral concentrates and the average beach sands (Neiheisel, 1962, p. 365). The process of heavy-mineral accumulation is accentuated by the progessive destruction of beach and barrier-island sediments along tidal inlets. When sediments are added to beach sequences, either by longshore drift or from fluvial action, the heaviest fraction of the sediment load is first deposited and the lighter fractions are moved on. As the beaches are being reworked, the heavy minerals are continuously being transported and sorted. This continuing process tends to eliminate all but the most stable heavy minerals. Lighter minerals may be intermixed from time to time with the heavier minerals as shoreline features change. Along the coastline, the overall effect through time will be to increase the concentration of heavy minerals, especially stable ones, as the coastline develops.

Heavy-mineral placers generally make up only a part of a relic beach deposit. In other parts of the beach, light minerals are more plentiful. Concentrations of heavy minerals can be extremely local, and in many places the heavier mineral content of the sand may be sparse. The outline of a heavy sand deposit can be either sharp or gradational. Although some heavy-mineral deposits are only a few feet long, minable heavy-mineral deposits range in length from about 0.5 to 18 miles and in width from about 0.1 to 2 miles. These deposits extend to depths from about 5 to 70 feet. The deposit at Boulogne is 2½ to 3 miles long and ½ to ¾ mile wide. It varies in thickness from 5 to 25 feet (Pirkle and others, 1974, p. 1129). The heavy-mineral deposit at Green Cove Springs is 10 to 12 miles long, is ¾ mile wide, and has an average thickness of about 20 feet (Pirkle and others, 1974, p. 1129). The largest known heavy-mineral deposit, at Trail Ridge, is approximately 18 miles long and 1 mile wide. It ranges in thickness from 25 to 70 feet (Garnar, 1972, p. 17). Most deposits, however, are smaller than those in these operating properties.

The heavy-mineral content of beach placers ranges from about 0.5 to 6 percent. Heavy minerals average from 3 to 4 percent of the sand deposits at Green Cove Springs and Boulogne (Pirkle and others, 1974, p. 1129) and 4 percent at Trail Ridge (Pirkle and Yoho, 1970, p. 17). Monazite makes up from almost nothing to about 2 percent of the heavy-mineral concentrates. Titanium minerals make up the greater part of the heavy minerals. Most are called ilmenite and leucoxene. The principal titanium mineral is referred to as ilmenite; but during the long weathering process, transportation, and deposition, most of the FeO may be changed to Fe_2O_3, and then the iron may be partially leached out of the mineral. This process leaves a cryptocrystalline mineral with an above-average TiO_2 content. If the titanium mineral has less than 65 percent TiO_2, it is referred to in the trade as ilmenite; if it contains 65 to 85 percent TiO_2, it is called leucoxene (Garnar, 1972, p. 18). Other heavy minerals commonly found are zircon, rutile, kyanite, staurolite, spinel, sillimanite, tourmaline, epidote, garnet, xenotime, corundum, and topaz. In all the deposits, more than 50 percent of the heavy minerals are titanium minerals. Zircon is ubiquitous and generally makes up 10–20 percent of the heavy minerals. Kyanite, staurolite, sillimanite, epidote, and garnet vary widely and may be relatively abundant in the heavy minerals in one placer and scant to absent in the next. The remaining minerals, including monazite, make up only a minor part of the total heavy minerals in any placer. An example of the mineral content of a heavy-mineral concentrate is reported on by Calver (1957, p. 18) from the property mined by the Rutile Mining Co., east of Jacksonville. This concentrate had an average composition of 40 percent ilmenite, 4 percent leucoxene, 7 percent rutile, 11 percent zircon, 0.5 percent monazite, and 37.5 percent other minerals (mainly sillimanite, kyanite, and staurolite).

Monazite is principally a rare-earth mineral, commonly containing 60–63 percent total rare-earth oxides. The ThO_2 content can be highly variable, but the range is apparently small for the monazite found in beach placers in Florida. Kremers (1958, p. 2) reported that Florida beach placers contained 4.5 percent ThO_2. Calver (1957, p. 25) noted that the average of five analyses of monazite from heavy minerals on Amelia Island, St. George Inlet, Mayport, Ponte Vedra, and Anastasia Island was 4.96 percent ThO_2. Monazite concentrates from the mining operations at Boulogne and Green Cove Springs each had 4.44 percent ThO_2. The ThO_2 content of beach sands is quite low, and the amount found in raw sand from which recovery of monazite is likely is on the order of 0.0003–0.004 percent ThO_2.

Monazite also contains small amounts of uranium, and the average U_3O_8 content of the five samples reported on above by Calver (1957, p. 25) is 0.55 percent. The monazite concentrate from Boulogne had 0.42 percent U_3O_8, and that from Green Cove Springs, 0.47 percent U_3O_8.

The economic feasibility of any beach placer is determined primarily by its TiO_2 content. In the 1970's the minimum TiO_2 content used as a cutoff in mining was 1 percent, and the TiO_2 content of sands being mined was from 1 to 1.5 percent. The amount of various titanium minerals (ilmenite, leucoxene, or rutile) present and their TiO_2 content are also important economic considerations. The TiO_2 content is greater in the older beaches (those farther inland), primarily because of increased leaching of iron from ilmenite and the conversion of ilmenite to leucoxene (J. L. Hetherington, Humphrey Mining Corporation, oral commun., 1978). Thus, the TiO_2 content may be as much as 15 percent greater in the placer beaches of the Effingham sequence than in those of the Chatham sequence.

ThO_2 resources in Florida occur in many Pleistocene beach deposits. As noted previously, the amount of ThO_2 is quite small and its recovery is dependent on monazite being recovered as a byproduct during the mining of other heavy minerals. The total heavy-mineral content of the various placers commonly makes up only 2–4 percent of the total sand in the deposits. Hence, beach-placer mining is a relatively large volume-low margin operation. In the 1970's, to begin a mining operation on a large scale would take an estimated reserve of 1,000,000 short tons of heavy minerals. A small, experienced company might be able, on a smaller scale, to develop a deposit that had half that amount of reserves. Thus, reserves of many small beach deposits add little to the minable resources of ThO_2. In this paper we have, therefore, included as reserves only those deposits containing 500,000 tons or more of heavy minerals. Some of the beach placers are covered by from 1 to 40 feet of barren dune sand. Resources in these areas can only be ascertained by drilling. Further exploration will undoubtedly increase the ThO_2 resources in Florida.

We have evaluated five large beach placers in the northern part of this State. These do not include the large Trail Ridge deposit, which does not contain more than traces of monazite, or the Boulogne or Jacksonville deposits, which are for the most part mined out. Data are mainly from drill holes. As this information is company-confidential, we have consolidated the figures and give only the totals for all deposits. Total reserves are 16,200 short tons of ThO_2 in 364,000 tons of monazite. This monazite also contains 1,640 tons of U_3O_8 and 218,000 tons of total rare-earth oxides. In addition, these deposits also contain 3,930,000 tons of ilmenite, 740,000 tons of rutile, and 590,000 tons of zircon. The heavy minerals from which this monazite is derived make up from 2.7 to 4.1 percent of the beach placers. Reserves make up the greater part of the resources, as most of these deposits have been drilled out. The category of probable potential resources in a relatively undrilled extension has 5,120 short tons of ThO_2 in 115,000 tons of monazite. This monazite also contains 520 tons of U_3O_8 and 69,000 tons of total rare-earth oxides. Other heavy minerals present include 890,000 tons of ilmenite, 157,000 tons of rutile, and 81,700 tons of zircon. These resources represent minimum resources, as several other known heavy-mineral Pleistocene placers exist for which the drilling data are not available. In addition, many Pleistocene strand lines, especially in central Florida, have yet to be carefully explored.

Cost studies also were made on placer sands by Jim F. Lemons, Jr., Louis V. Coppa, and Benjamin V. Clingan of the U.S. Bureau of Mines (Staatz and others, 1979). Cost calculations made by operators of monazite placers go only as far as the separation of the individual heavy minerals. We have carried this one step farther and have included the separation of the ThO_2 from the monazite in order to have a basis for comparing the cost of ThO_2 between different types of deposits. The cost calculation covers the mining of the sand and its processing through three separate mills. In the first mill, the heavy minerals are separated from the beach sands; in the second, monazite and various other heavy minerals are separated from each other; and in the third, thorium, uranium, and rare earths are recovered from the monazite.

Although beach placers are an extremely low-grade source of ThO_2, several factors aid in making this type of mining feasible. First, they are large in size; second, they have only a few feet of overburden and can be mined by open pit; third, they are loose, fairly well-sorted sand and need neither blasting during mining nor grinding and sorting during milling; and fourth, the water table is high enough in northern Florida so that they can be mined by a dredge floating on a pond. The first step is to make a pond into which to put the dredge. A hydraulic dredge having a rotating cutter head is used to loosen the alluvium, and the sediment is pumped to the surface. From there it is pumped through a pipeline floating on pontoons either to a floating heavy-mineral mill or to a mill on land.

The mining costs are divided into capital and operating costs. Capital costs include mine development, mining plant, and equipment. These costs do not include those for exploration, acquisition of land, or obtaining working capital, because these costs have not been considered in comparative cost calculations for uranium. Most development costs include clearing trees and brush from the placer deposit, building roads, and digging the initial pond with a dragline. Mining-plant costs include the dredge and any buildings needed for the operation. Equipment costs include all equipment and supplies necessary to bring the property into production. Operating costs are divided into direct, indirect, and fixed costs. Direct costs apply directly to the dredging operation and include labor, supervision, power and fuel consumption, cutter bits, and supplies. The indirect costs are for administrative and clerical help, facility supplies, and general overhead. Fixed costs are for local taxes and insurance. These costs are a function of the capital costs and are estimated to be 3 percent of capital costs.

Milling of placer sands is a fairly well-known process. In the first mill, which is attached to the dredge, the various heavy minerals are separated from the rest of the alluvium. This separation is made with spiral gravity separators, the common method used for separating heavy minerals from beach sands in Florida. The heavy sands go through three series of spirals—roughers, cleaners, and finishers—and the finished product is dewatered. The heavy concentrate makes up only about 2–4 percent of the alluvium mined. The rest of the alluvium is returned to the end of the pond through a moving pipe that spreads it evenly into the valley bottom so that it can quickly be returned to its original agricultural use. The concentrates are trucked to a dry mill, where the various heavy minerals are separated from each other using magnetic and electrostatic separators.

ThO_2 is extracted from the monazite in a leach-solvent plant. This plant extracts not only the thorium from monazite, but also recovers uranium and rare earths.

The milling costs for each mill are divided into capital and operating costs. Capital costs for each mill consist of the cost of building the mill and the cost of the equipment that is necessary to make it operational. The size of the mill is the principal factor that affects the original cost of the mill. The proposed gravity mills are designed to handle from 2,300 to 22,000 tons of sediments per day for an operating life of at least 15 years. The magnetic-electrostatic mills proposed for these deposits are designed to handle from 230 to 615 tons of heavy concentrates per day. The life of this type of mill, assuming the most efficient use of all the equipment, would be at least 15 years. The leach-solvent mill is a much smaller plant, and the proposed design can be used for a plant having an input of from 5 to 8 tons of monazite per day. This plant also is most efficient if it has a life of at least 15 years.

The operating costs for milling can be divided into direct, indirect, and fixed costs. The direct costs include fuel and power consumption, reagents, labor, supervision, and supply maintenance. The indirect costs are those for administration, technical and clerical help, facility maintenance, office supplies, and general overhead. Fixed costs are for local taxes and insurance on the milling facilities. The principal variable in a mill's operating cost is its capacity.

Cost calculations were made on all five placer deposits. The reserves at three of these deposits can be produced for less than $15/lb of ThO_2. These deposits have reserves of 15,800 short tons of ThO_2 that are contained in 356,000 tons of monazite. This monazite also contains 1,600 short tons of U_3O_8 and 214,000 tons of total rare-earth oxides. A fourth deposit has reserves of 190 short tons of ThO_2 that can be produced for between $15 and $30/lb. This ThO_2 is in 4,250 tons of monazite. The monazite also has 19 tons of U_3O_8 and 2,550 tons of total rare-earth oxides. The remaining placer has reserves of 168 short tons of ThO_2 that could be produced for between $30 and $50/lb. This ThO_2 is contained in 3,770 tons of monazite, which also contains 17 tons of U_3O_8 and 2,260 tons of total rare-earth oxides. The probable potential resources, found in only one deposit, could be produced for less than $15/lb. This tonnage is 5,120 short tons of ThO_2, which occurs in 115,000 tons of monazite. The monazite also contains 520 tons of U_3O_8 and 69,000 tons of total rare-earth oxides. If only ThO_2 were recovered from these beach sands, then the cost of producing it would be considerably in excess of $50/lb. Thus, the recovery of ThO_2 in these deposits is dependent on recovering other heavy minerals, although a price for ThO_2 comparable with that for U_3O_8 would undoubtedly permit some otherwise marginal heavy-mineral deposits to go into production.

IDAHO STREAM PLACERS

GENERAL

Stream placers in Idaho are found principally along the west side of the Idaho batholith, north of Boise. Monazite is the principal thorium-bearing mineral in most of these placers. It was first identified in 1896 by Waldemar Lindgren (1897a, 1897b) in the heavy "yellow sand" that accumulated in the sluices of the placer gold mines in the Boise Basin around Idaho City, Centerville, and Placerville. Lindgren also recognized the economic potential of monazite and suggested that, if market conditions permitted, it might be profitably recovered as a byproduct of placer gold. In 1909 a mill was constructed to produce monazite by the Centerville Mining and Milling Co. Only token quantities of monazite concentrate were produced during the initial shakedown of the plant, and it was destroyed by a forest fire in 1910. Two placer areas were mined for radioactive minerals in the 1950's: Long Valley and Bear Valley.

In Long Valley, monazite was recovered by three dredges over a 5-year period. Dredging began in September 1950 in the Big Creek section of Long Valley by Baumhoff-Marshall, Inc. During the summer of 1951 two dredges—one of the Idaho-Canadian Dredging Co., the other of the Warren Dredging Co.—started operation. All three dredges were formerly used for recovering gold. They were refitted for monazite recovery with help from the U.S. Bureau of Mines under the sponsorship of the U.S. Atomic Energy Commission. The Warren dredging operation was relatively short-lived as this dredge capsized in 1953 and was not put back into operation. Crude black-sand concentrates were recovered by jigs mounted on the dredges. These concentrates were dewatered and hauled to Boise to a magnetic-electrostatic separation plant operated by Baumhoff-Marshall Inc. Part of the monazite was sold to the government stockpile and part to commercial monazite processors. Mining ceased in mid-1955 due to the filling of the government stockpile order (Eilertsen and Lamb, 1956, p. 25) and to increased foreign competition. An excellent summary of the Big Creek operations as of late 1953 is given by Argall (1954).

The amount of heavy minerals produced by the three dredges has not been published. However, on the basis of known dredge capacities, time in operation, and estimates of the amount of placer material mined, the quantities of monazite and other heavy minerals recovered can be approximated (table 2). These figures suggest that the three dredges recovered 7,085 short tons of monazite containing 297 tons of ThO_2.

The other area in which thorium was produced is Bear Valley. This placer, although containing two principal radioactive minerals (euxenite and monazite), was operated principally for its niobium and tantalum content. Euxenite also contains thorium and uranium. The Porter Brothers Corp. obtained a contract to provide 1,050,000 pounds of niobium-tantalum oxide for

TABLE 2.—*Estimated amount of placer material dredged and amounts of monazite and other heavy minerals produced by three dredges in the Big Creek part of Long Valley*

[Based in part on material derived from Argall, 1954]

Dredge operator	Period of operation	Cubic yards dredged	Heavy minerals recovered				ThO_2 content of monazite in short tons
			Monazite	Ilmenite	Zircon	Garnet	
Baumhoff-Marshall, Inc.	9/50-8/55	6,380,000	3,510	38,300	1,280	2,230	147
Idaho-Canadian Dredging Co.	8/51-8/55	5,400,000	2,970	32,400	1,080	1,890	125
Warren Dredging Co.	9/51-5/53	1,100,000	605	6,600	220	390	25
Total	9/50-8/55	12,880,000	7,085	77,300	2,580	4,510	297

the General Services Administration stockpile. They began production with one dredge in 1955, and followed it with a second dredge in 1956. Black-sand concentrate was recovered by jigs mounted on the dredges. The crude concentrate was hauled 22 miles to Lowman, where relatively clean concentrates of euxenite, columbite, and monazite, and less clean concentrates of magnetite, ilmenite, garnet, and zircon were produced in an electromagnetic-electrostatic plant. Dredging ceased in October 1959 with the fulfilling of the General Services Administration contract. During the operation, approximately 6,500,000 cubic yards of placer material was dredged (Richard B. Porter, written commun., 1958). From alluvium of Bear Valley, 2,049 short tons of euxenite, 83.5 tons of columbite, and 54,862 tons of ilmenite were recovered. Records are not available on the amount of monazite recovered.

The greater part of the resource data on Idaho placers was obtained during a program to find new domestic monazite reserves by the U.S. Bureau of Mines using funds obtained from the U.S. Atomic Energy Commission. The program was a result of an embargo placed by Brazil and India on monazite, as these countries wished to save their thorium as an eventual atomic energy source (Eilertsen and Lamb, 1956, p. 4). The embargo effectively cut off the United States from their major sources of thorium ores. The program was carried out in Idaho, principally by the Bureau of Mines, between 1949 and 1954. During this period the Bureau explored 27 placers in Idaho, of which 9 were considered to have potential economic reserves (Storch and others, 1956, p. 9). The Bureau of Mines has published data on most but not all of the placers they examined. They reported on a total of 12 placer areas, including the most important ones: (1) Bear Valley (Kline and others, 1953), (2) Beaver Creek (Storch and Robertson, 1954), (3) Big Creek (Kline and others, 1951a), (4) Boise Basin (Kline and others, 1950), (5) Camp Creek (Robertson and Storch, 1955a), (6) Corral Creek (Kline and others, 1955), (7) Deadwood (Storch, 1958b), (8) Gold Fork (Storch, 1958a), (9) Horsethief Basin (Kline and others, 1951b), (10) Pearsol Creek (Kline and Carlson 1954), (11) Rock Creek (Robertson and Storch, 1955b), and (12) Scott Valley (Kline and others, 1951b). Seven of these placers (Big Creek, Beaver Creek, Corral Creek, Gold Fork, Horsethief Basin, Pearsol Creek, and Scott Valley) are placers formed by streams flowing into Long Valley and are considered in this report as part of Long Valley district. The report on the Boise Basin, on the other hand, contains a description of six separate placers. These deposits were explored by a variety of methods, including churn drill holes, trenching, small shafts, and dredge sampling. Shaft sinking and trenching were important methods used to obtain bulk samples for analysis of average mineral contents. Drilling gave data on depth and extent of the placer. The Bureau of Mines in the above-reported projects drilled 542 holes from 5 to 140 feet deep, for a total of 22,072 feet of drilling, and collected over 210 tons of samples. In addition, a few placers have been explored under Defense Minerals Exploration Administration contracts; and one such area, the Dismal Swamp placer in Elmore County,

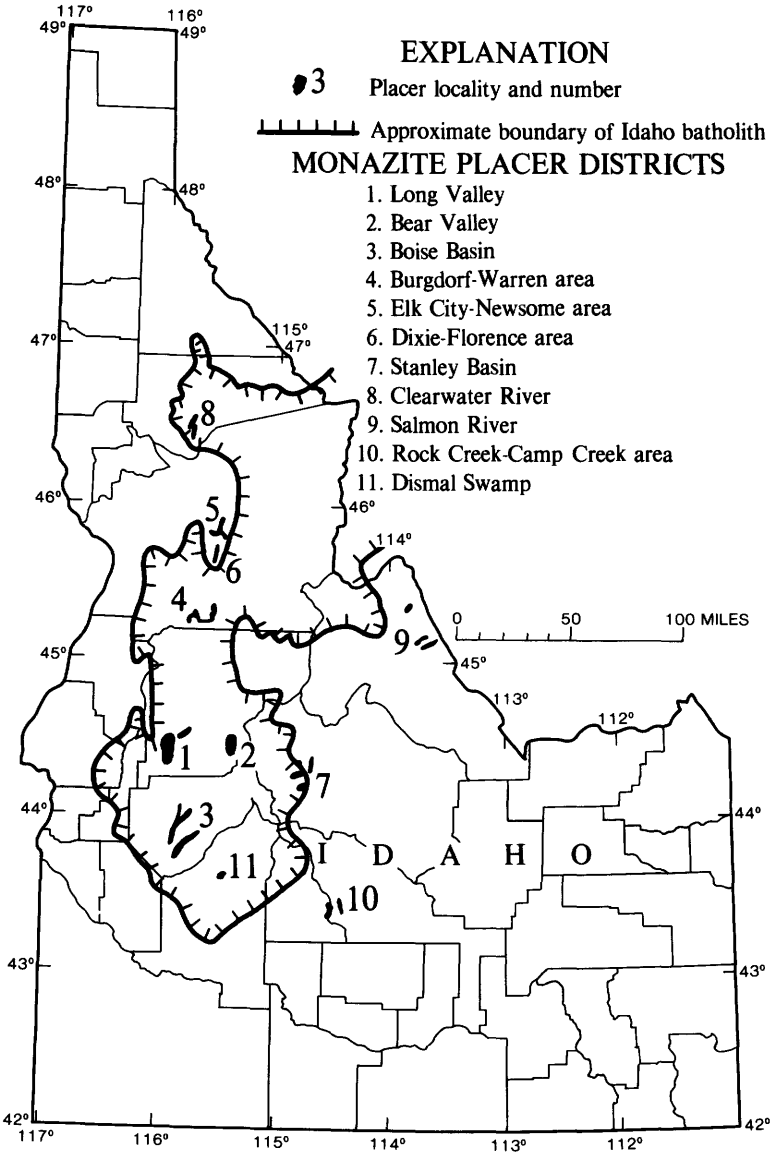

FIGURE 1.—Map showing location of the principal stream placers in Idaho.

is reported on by Armstrong (1955).

The present study of Idaho placers included review of the literature, interviews with people connected with former dredging operations, and field reconnaissance of all major placer districts reported to have commercial possibilities as thorium sources. In addition, samples of placer alluvium, dredging tailings, and panned concentrates were taken for future mineralogic and economic studies.

Thorium has been reported from many placer deposits in Idaho. The five most important districts are (1) Long Valley in Valley County, (2) Bear Valley in Valley County, (3) Burgdorf-Warren area in Idaho County, (4) Boise Basin in Boise County, and (5) Elk City-Newsome area in Idaho County (fig. 1). Six other less promising districts contain significant amounts of monazite or other thorium-bearing minerals. These districts, and their numbers as shown in figure 1, are (6) Dixie-Florence area, (7) Stanley Basin, (8) Clearwater River, (9) Salmon River, (10) Rock Creek-Camp Creek area, and (11) Dismal Swamp. Monazite has been reported in other parts of the State in and adjacent to the Idaho batholith, but the resource potential in these other areas appears low. Long Valley and Bear Valley are the two most important areas for mining thorium-bearing minerals.

The major source of thorium-bearing minerals in the placer deposits is the Idaho batholith. Monazite is by far the most common thorium-bearing mineral and has been found in many parts of the batholith (Mackin and Schmidt, 1957, p. 2). The monazite is disseminated in the igneous rock as tiny grains, most of which are less than 0.5 mm across. Other thorium-bearing minerals, such as euxenite and uranothorite, tend to be local in their distribution and occur mainly in veins or pegmatite bodies rather than dispersed within the batholith like monazite. The distribution of the monazite in the granitic rock of the Idaho batholith is erratic. Samples collected from the granitic rock in the drainage basins adjacent to Long Valley varied in monazite content from 1 to 0.3 pound per cubic yard (Mackin and Schmidt, 1957, p. 2). Heavy minerals weather out of the granitic rocks of the Idaho batholith and are washed downslope into the stream bottoms, where the heavy minerals tend to form placers fairly near their sources. Most of the placers that form along stream bottoms are narrow, fairly shallow, and not of sufficient size to support a large-scale dredging operation. To be economically minable, a thorium placer deposit must contain a large volume of alluvial fill that can sustain large-scale dredging operations over a period of years. Such large-volume deposits occur not as narrow, shallow veneers of sand and gravel on creek bottoms, but rather in broad basins (such as Long Valley and Bear Valley). In Idaho, such basins have been formed by (1) block faulting (2) damming of streams by glacial deposits, and (3) damming of streams by basalt flows of Pleistocene age (Mackin and Schmidt, 1957, p. 2). Block faulting during Pleistocene time deranged the drainage and developed Long Valley. A glacial moraine dammed a creek, forming a basin at Bear Creek Valley and leading to the subsequent development of a large placer in Big Meadows. A basalt flow cutting across the drainage lines near Hailey helped form the Rock Creek-Camp Creek uranothorite placers in that area.

Placers in Idaho range widely in size. The largest volume of minable placer ground is found in Long Valley, where alluvium fill underlies an area of more than 5 mi^2. Another large placer, that in Bear Valley, has a length of 14 mi and a width varying from 650 to 6,000 ft. The Grimes Creek and Mores Creek placers in the Boise Basin are 10 miles long by 600 ft wide and 7¾ mi long by 700 ft wide, respectively. Other placers are considerably narrower and contain less placer material. A fairly typical example is near Elk City, where a placer along a 10-mile stretch of the American River only locally exceeds 200 ft in width.

Depth of deposits also shows a large range, from those in deep down-faulted valleys to those in shallow rock-carved stream basins. In Long Valley, where faulting continued during the Pleistocene, a thick wedge of monazite-bearing sediments has a maximum depth of several thousand feet (Mackin, 1952, p 19). The deepest drill hole in this valley is 123 feet at Corral Creek (Kline and others, 1955, p. 14). Depth of the placer in upper Bear Valley is from less than 10 to over 100 feet, with an average of about 40 feet. In the Boise Basin, the Grimes Creek placer has an estimated average depth of about 28 feet, and the Mores Creek placer has an average depth of about 25 feet. Other dredgable placers commonly have average depths of from 10 to 15 feet.

The average heavy-mineral content of various Idaho placers sampled by the U.S. Bureau of Mines ranges from 0.10 to 1.06 percent of the placer sediments and averages about 0.5 percent. Rock Creek placer in Blaine County (Robertson and Storch, 1955b, p. 18–19) and Bear Valley placer in Valley County (Kline and others, 1953, p. 14–16), with 1.06 and 1.01 percent heavy minerals respectively, have the greatest known amounts of heavy minerals. Five placers that occur in Long Valley have a heavy-mineral content of from 0.23 to 0.70 percent (Kline and others, 1951a, p. 17; 1951b, p. 17; Kline and Carlson, 1954, p. 18–19; and Kline and others, 1955, p. 17). Heavy-mineral content commonly varies between individual samples, and samples from 65 drill holes at the Pearsol Creek placer in Long Valley had from 0.072 to 2.55 percent heavy mineral, with an average of 0.54 percent (Kline and Carlson, 1954, p. 11, 18, 19). The average monazite content makes up from a trace to 16 percent of the heavy minerals in the various placers. Monazite is most abundant in the Corral Creek placer in Long Valley (Kline and others, 1955, p. 17). Camp Creek and Rock Creek in Blaine and Camas Counties, which have only traces of

TABLE 3.—*Mineral content, in percent, of heavy minerals from three placers*

Mineral	Pearsol Creek	Bear Valley	Camp Creek
Monazite..........	8.4	3.6	0.1
Euxenite..........	Trace	.14-.3	0
Uranothorite......	0	0	1.2
Ilmenite..........	80.5	58.6	26 -30
Zircon............	.1	.07	.5- .8
Garnet............	1.6	20	.2
Magnetite.........	.7	10.3	29 -33
Sphene............	0	1.0	10 -12

monazite, contain thorium in uranothorite. Uranothorite makes up about 1.2 percent of the heavy minerals in the Camp Creek placer (Robertson and Storch, 1955a, p. 24) and 0.45 percent in the Rock Creek placer (Robertson and Storch, 1955b, p. 22). The placer in Bear Valley contains thorium and uranium in euxenite. Euxenite makes up approximately 0.5 percent of the heavy minerals in upper Bear Valley (Kline and others, 1953, p. 17-19). Ilmenite may be the most common heavy mineral, and in individual placers its average abundance ranges from about 14 to 95 percent of the heavy minerals. Zircon is a common constituent of the heavy minerals, but varies greatly in amount in different placers. It makes up only 0.11 percent of the heavy minerals in Bear Valley (Kline and others, 1953, p. 17-19) but makes up 23 percent of the Wolf Creek placer in Boise Basin (Kline and others, 1950, p. 17). Garnet, another possible economic mineral, ranges from a trace to 54 percent of the heavy minerals in different placers. The variation in some of the more common heavy minerals was compiled by Storch and others, (1956, p. 14) (table 3). In addition to the above-mentioned minerals, other heavy minerals occurring in various placers in generally minor amounts are hematite, pyrite, biotite, amphibole, pyroxene, epidote, rutile, anatase, cassiterite, allanite, columbite, samarskite, topaz, xenotime, and gold. Gold has been recovered from placers in the Boise Basin, Burgdorf-Warren, and Elk City districts and from other placers; it is a potential byproduct of monazite in these placers. Gold, however, is sparse to absent in the most promising thorium-bearing placers of Long Valley and Bear Valley.

The ThO_2 content of monazite in the Idaho placers varies from 2.2 (Staley, 1952, p. 308) to 6.24 percent (Kauffman and Baker, 1956, p. 6). The amount of ThO_2 in the monazite, in general, seems to increase southward in Idaho (Overstreet, 1967, p. 142). The ThO_2 content of monazite in the larger placers (Long Valley and Bear Valley) varies from about 4.1 to 4.7 percent (Kline and others, 1955, p. 18; Kline and others, 1951, p. 19; Kline and Carlson, 1954, p. 21-22; Kline and others, 1953, p. 20; Kline, and others, 1951a, p. 21-22). Average ThO_2 content of monazite from the Boise Basin is 3.2 percent (Kline, and others, 1950, p. 32). Only a few analyses are available on the total rare-earth-oxide content of monazite from Idaho. These analyses indicate that monazite from this area has approximately 63 percent total rare-earth oxides (Overstreet, 1967, p. 146-159).

Monazite also contains small amounts of uranium, and the U_3O_8 content of monazite from Idaho varies from 0.10 to 0.36 percent. The monazite in most of the larger placers in Long Valley contains only 0.1 to 0.15 percent U_3O_8.

As euxenite is an important mineral in the Bear Valley placer, its chemical composition is also important. Two samples of euxenite had an average ThO_2 content of 4.97 percent (Kline and others, 1953, p. 20). They also contained 14.40 percent U_3O_8, 25.0 percent Nb_2O_5, and 3.0 percent Ta_2O_5.

In the past, placers in Idaho were mined mainly for the gold. A few placers were dredged for monazite or euxenite. Although most of the high-grade gold deposits have been exhausted, only a minor part of the thorium resources has been recovered. Much of the thorium resources occur in a few large placers in unmined areas, but some are found in old tailings piles left by early operators dredging for gold. Virtually all placers in the central part of Idaho are composed of sediment which originated from the Idaho batholith, and this sediment contains some monazite. Although monazite may be recognized in sediments of more than a hundred streams, only a few have large enough resources to be mined by dredges. Over 90 percent of all the resources estimated is in the three largest deposits. The principal placer-thorium resources of Idaho are in five districts, named in order of relative importance: (1) Long Valley, (2) Bear Valley, (3) Warren-Burgdorf, (4) Boise Basin, and (5) Elk City-Newsome. Most of these areas consist of several adjacent placers in the same drainage or valley. The largest, Long Valley, is a large downfaulted valley filled with sediments from several streams that flow into it.

The U.S. Bureau of Mines explored a number of heavy-mineral placer deposits in Idaho during the early 1950's (Eilertsen and Lamb, 1956; Storch and Holt, 1963). Although the Bureau's published reports give useful data on areas covered, depths of drill holes, and mineral tenors, they do not give information on volumes of the deposits. We have estimated volumes by measuring areas on topographic maps with a polar planimeter and multiplying the area figure by an average-depth figure obtained by averaging drill-hole depths given in the Bureau's reports. For those districts where published drilling reports by the Bureau are not available, as for the Warren-Burgdorf and Elk City-Newsome districts, the average depths have been estimated conservatively from older published reports by Idaho Bureau of Mines and Geology, that mention dredging depths or give other information on which to base estimates of probable average depths (Capps, 1940; Reed, 1937; and Reid, 1960). The Bureau's drilling patterns for the larger areas were laid out in rectangular form on lines spaced 800–1,600 feet apart. The holes were spaced 600–800 feet apart on the lines. Drilling on smaller, irregularly shaped areas was done at selected points ranging from 400 to 1,000 feet apart (Eilertsen and Lamb, 1956, p. 18).

Reserves are distinguished from probable potential resources by depth of drilling. Reserves are that part of the resources that have been drilled out. Many holes were bottomed at the base of the placer in country rock. In these cases there are no probable potential resources. Elsewhere, those sediments lying below the depth of drilling but no deeper than 130 feet were considered probable potential resources. The deposits in Long Valley may extend to a depth of several thousand feet (Mackin, 1952, p. 19), which is a much greater depth than can be mined by the largest dredge. As these deposits are both long and wide, a large dredge could operate in this valley. Daily (1968, p. 507) reported dredging to depths of 158 feet in Malaysia. We have chosen 130 feet as the lower limit of our probable potential resources. This figure, which is only used in Long Valley, is a compromise figure between the depth obtained by local dredges and that which has been obtained by dredges in other parts of the world. Two of the placer areas, Bear and Long Valleys, have been in part dredged previously. The dredged-out areas are not included in the resource calculations. In Bear Valley, perhaps 10 percent of the total reserves have been mined; the percentage in Long Valley is even less. Total reserves are 10,062 short tons of ThO_2 (table 4). This ThO_2 is in 227,000 tons of monazite and 9,760 tons of euxenite. The monazite also contains 380 tons of U_3O_8; the euxenite contains approximately 1,410 tons of U_3O_8. The reserves of many small placers are not included in our total reserve figure, but they would not greatly increase this figure. However, some areas in Long Valley have not been explored, and additional reserves might be found in this area.

Total probable potential resources, all from Long Valley, are 10,320 short tons of ThO_2 (table 4). This ThO_2 is in 237,000 tons of monazite. The monazite also contains 404 tons of U_3O_8.

Cost studies were made on fluviatile placer deposits by Jim F. Lemons, Jr., Louis V. Coppa, and Benjamin V. Clingan of the U.S. Bureau of Mines (Staatz and others, 1979). Mining of these deposits would be done using a dredge floating on a pond, as has been done in the area in the past. The dredge would deliver sand to a floating mill, either on the same or a separate barge. The heavy minerals would be separated here and the light minerals returned to the far end of the pond. A hydraulic dredge with a rotary cutting head would be used to loosen the alluvium, which then would be pumped to the surface. The heavy minerals would be trucked to a nearby magnetic-electrostatic mill, in which the various heavy

TABLE 4.—*ThO_2 reserves and probable potential resources, in short tons, from various placer districts in Idaho*

Placer district	Total reserves	Total probable potential reserves	Total producible at less than $15/lb		Total producible at between $15 and $30/lb		Total producible at between $30 and $50/lb	
			Reserves	Probable potential resources	Reserves	Probable potential resources	Reserves	Probable potential resources
Long Valley	5,680	10,320	3,500	6,560	1,670	3,760	513	0
Bear Valley	1,605	0	1,140	0	465	0	0	0
Burgdorf-Warren area	1,940	0	0	0	1,660	0	284	0
Boise Basin	660	0	0	0	0	0	0	0
Elk City-Newsome area	177	0	0	0	0	0	0	0
Total	10,062	10,320	4,640	6,560	3,795	3,760	797	0

minerals would be separated from one another. In this plant, not only monazite and (or) euxenite would be separated from the other heavy minerals, but several byproducts, such as ilmenite, zircon, and garnet, could be obtained as well. Although these minerals would be the final product sold by the operator from these placers, we have added the cost of a separate leaching mill from which ThO_2 and U_3O_8 would be extracted from the radioactive minerals. This added step was necessary so that the cost of producing ThO_2 from a placer could be compared directly with that of producing it from a vein. The type of mining and milling costs used in these calculations are the same as those described in the section on Florida beach placers.

Cost calculations were made on the placers of all five principal areas (table 4). Two of the areas (Long and Bear Valleys) have reserves producible at less than $15/lb. These deposits have reserves of 4,640 short tons of ThO_2 and 1,380 tons of U_3O_8 that are contained in 96,500 tons of monazite and 8,360 tons of euxenite. Three areas (Long and Bear Valleys and the Burgdorf-Warren area) have reserves producible at between $15 and $30/lb. These placers have reserves of 3,800 short tons of ThO_2 and 335 tons of U_3O_8 that are contained in 82,900 tons of monazite and 1,400 tons of euxenite. Two areas (Long Valley and the Burgdorf-Warren area) have reserves producible at between $30 and $50/lb. These deposits have reserves of 797 short tons of ThO_2 and 25 tons of U_3O_8 that are contained in 19,800 tons of monazite. None of the reserves in any of the placers in the Boise Basin or the Elk City-Newsome area are producible at less than $50/lb. Probable potential resources are only found in the Long Valley placers. Here the tonnage that may be producible at less than $15/lb is 6,560 short tons of ThO_2 in 152,000 tons of monazite. In addition, 3,760 tons of ThO_2 may be producible at between $15 and $30/lb. This amount of ThO_2 occurs in 85,700 tons of monazite.

The principal product of the Idaho stream placers, unlike the situation in the Florida beach placers, would be the thorium- and uranium-bearing minerals, monazite and (or) euxenite. Other minerals, such as ilmenite, zircon, or garnet, would only be of secondary interest. The euxenite in Bear Valley, which contains approximately three times as much uranium as thorium, also contains niobium. Niobium, although not taken into account in our cost calculations, would be a significant source of income in Bear Valley.

LONG VALLEY

Long Valley resources have been divided into areas adjacent to the individual streams that flow across Long Valley. The greater part of these resources is adjacent to Big Creek (where the dredging in the 1950's was done) (Kline and others, 1951a), Pearsol Creek (Kline and Carlson, 1954), Corral Creek (Kline and others, 1965) and Scott Valley (Kline, and others, 1951b). Another promising placer was explored in Horsethief Basin (Kline and others, 1951b), but as this placer is now covered by a reservoir, its resources are not included. Other parts of Long Valley lie adjacent to the areas of exploration. Although data are not available on these parts, the sediments here probably contain monazite. We have not in-

TABLE 5.—*ThO_2 reserves and probable potential resources, in short tons, from placer areas in Long Valley*

Placer deposits	Total resources	Total probable potential reserves	Total producible at less than $15/lb: Reserves	Probable potential resources	Total producible at between $15 and $30/lb: Reserves	Probable potential resources	Total producible at between $30 and $50/lb: Reserves	Probable potential resources
Big Creek	1,350	2,690	1,350	2,690	0	0	0	0
Pearsol Creek	2,150	3,870	2,150	3,870	0	0	0	0
Corral Creek	1,670	3,760	0	0	1,670	3,760	0	0
Scott Valley	513	0	0	0	0	0	513	0
Total	5,683	10,320	3,500	6,560	1,670	3,760	513	0

cluded these unexplored areas in our calculations, but parts of these areas could conceivably add significantly to the overall thorium resources in Long Valley.

The reserves and probable potential resources of ThO_2 for four principal placer areas in Long Valley and amounts that can be produced in several cost categories are given in table 5. The 5,683 short tons of ThO_2 reserves would be recovered from 132,000 tons of monazite; the 10,320 tons of ThO_2 in probable potential resources is contained in 237,000 tons of monazite. In addition, the monazite in the reserves would also contain 180 tons of U_3O_8 and 82,800 tons of total rare-earth oxides. The monazite in the probable potential resources would contain 344 tons of U_3O_8 and 150,000 tons of total rare-earth oxides. Other heavy minerals that could be recovered from the reserves include 1,040,000 short tons of ilmenite, 23,700 tons of zircon, and 61,200 tons of garnet. The amounts of other heavy minerals in the probable potential resources are 2,450,000 tons of ilmenite, 47,700 tons of zircon, and 145,000 tons of garnet. Monazite is the principal economic mineral in these deposits. If a market were readily available for all heavy minerals and ThO_2 were marketed for $15/lb, then the value of monazite would make up 65–90 percent of the total value of the Long Valley deposits. If the price for ThO_2 were greater, then the value of monazite would make up an even larger percentage of the total value of the economic minerals.

BEAR VALLEY

Bear Valley Creek is a headwaters stream and an important tributary of the Middle Fork of the Salmon River. Placer deposits occur in three contiguous areas along at least 20 miles of this creek. These areas are called the Upper (Big Meadows area), Middle, and Lower Bear Valley areas. Bear Valley is unique among Idaho placers because, in addition to monazite, it also has economically significant amounts of euxenite. This mineral is derived locally from a 6-square-mile area of quartz diorite in the Idaho batholith (Mackin and Schmidt, 1957, p. 3). Euxenite is a hard, brittle mineral that breaks up fairly easily during downstream transportation. Mackin and Schmidt (1957, p. 6) noted that the larger euxenite grains decrease in size by three to four times within the first mile of movement downstream. Thus, the euxenite is principally concentrated in the Big Meadows area close to its source. Drilling by the U.S. Bureau of Mines (Kline and others, 1953) in the three areas indicates that the upper or Big Meadows area has the best tenor of heavy minerals. In the Middle Bear Creek placer, the grade of the monazite and euxenite is about half that found in Upper Bear Valley. In the Lower Bear Creek placer, only negligible amounts of thorium-bearing minerals occur in the alluvial sediments. Because of the low grade of thorium-bearing minerals, Lower Bear Valley is not considered further in this report. Most drill holes in Bear Valley went entirely through the placer, so we do not have any underlying probable potential resources. Resources of the Bear Valley placers differ from those in other Idaho placers in that they contain as much U_3O_8 as ThO_2. In addition to the small amount of U_3O_8 found in monazite, significant amounts of this oxide occur in euxenite. Kline and others (1953, p. 20) reported the average U_3O_8 content of two euxenites from Bear Valley to be 14.4 percent. The reserves of ThO_2

TABLE 6.—*ThO_2 and U_3O_8 reserves, in short tons, in placer areas of Bear Valley*

Placer	ThO_2 reserves	U_3O_8 reserves	Total ThO_2 producible at less than $15/lb	Total ThO_2 producible at between $15 and $30/lb	ThO_2 producible at between $30 and $50/lb
Upper Bear Valley..........	1,140	1,250	1,140	0	0
Middle Bear Valley..........	465	225	0	465	0
Total..........	1,605	1,475	1,140	465	0

and U_3O_8 for Upper and Middle Bear Valley placers and the amounts that can be produced in several cost categories are given in table 6. Total reserves of these two placers is 1,605 short tons of ThO_2 and 1,475 tons of U_3O_8, which are contained in 24,200 tons of monazite and 9,760 tons of euxenite. The two minerals also contain about 17,800 tons of total rare-earth oxides. In addition, the euxenite has about 2,440 tons of Nb_2O_5. Other heavy minerals that could be recovered from the reserves include 1,510 short tons of columbite, 391,000 tons of ilmenite, 940 tons of zircon, and 87,600 tons of garnet. Euxenite, monazite, and columbite are the principal economic minerals in these deposits.

BURGDORF-WARREN AREA

The Burgdorf-Warren area (fig. 1) is known for many gold placers, which have not been worked on a large scale since the early 1950's. The placers occur in stream valleys near the small communities of Burgdorf and Warren, which formerly were important gold-mining camps 10–12 miles south of the Salmon River. Significant quantities of monazite and other black-sand minerals occur in alluvium and old gold-dredge tailings in three areas: (1) Warren Meadows, (2) Secesh Meadows, and (3) Ruby Meadows. These broad meadows are thought to have been formed by block faulting (Savage, 1961, p. 112). In any reworking of these placers monazite would be the principal product, although a little gold missed during the previous operations also would be recovered. The largest of the three placer areas is at Warren Meadows, which contains approximately 39,000,000 cubic yards of alluvial material. The average monazite content of the three placers is between 0.033 and 0.044 percent. Monazite is reported to be the principal heavy mineral (Reed, 1937, p. 31–33; Capps, 1940, p. 34, 37). Garnet is also common. All the resources in these three placers are well enough defined to be included in reserves. Reserves in the three placer areas and amounts that can be produced in two cost groups are given in table 7. Total reserves for this area is calculated to be 1,940 short tons of ThO_2, contained in 43,500 tons of monazite. The monazite also contains 85 tons of U_3O_8 and 27,400 tons of total rare-earth oxides. At a January 1980 price of $650 per troy ounce, the Warren Meadows placer tailings contain approximately $1.59 cents worth of gold per cubic yard. The value of the gold was not taken into account in calculating the cost of producing a pound of ThO_2.

BOISE BASIN

The Boise Basin is a depression 15 miles long and 12 miles wide surrounded by tall mountains. This area is traversed by several branching streams which are separated by flat-topped, gently sloping ridges that rise a few hundred feet above the stream levels. Six placers scattered along these creeks have been described by the U.S. Bureau of Mines (Kline and others, 1950, p. 10). These placers are called (1) Grassy Flats, (2) Wolf Creek, (3) Fall Creek, (4) Granite Creek, (5) Grimes Creek, and (6) Elk and Mores Creeks. The greater part of the monazite-bearing sediments is in tailings left from early gold mining operations. Some areas of unworked placer ground remain on Wolf, Mores, and Fall Creeks and on Grassy Flats. The six placers have reserves totaling 660 short tons of ThO_2 in 20,700 tons of monazite. Reserves range in size from 49 tons of ThO_2 in the Wolf Creek placer to 240 tons of ThO_2 in the Grimes Creek placer. In addition to

TABLE 7.—*ThO_2 reserves, in short tons, from three placers in the Burgdorf-Warren area*

Placer	Total reserves	Total reserves producible at between $15 and $30/lb	Total reserves producible at between $30 and $50/lb
Warren Meadows..........	935	935	0
Secesh Meadows..........	725	725	0
Ruby Meadows............	284	0	284
Total...............	1,944	1,660	284

monazite, these placers contain 69,200 short tons of ilmenite, 27,300 tons of zircon, and 27,200 tons of garnet.

A maximum depth of 58 feet was obtained in one hole in the Wolf Creek placer (Kline and others, 1950, p. 31). The thickness of most placers is about 30 feet. The Bureau of Mines drilling in 1949 (Kline and others, 1950) reached bedrock in virtually all parts of the Boise Basin; therefore, there are no underlying probable potential resources.

The cost of producing ThO_2 from any of the six placers, even with the aid of byproducts, would be greater than $50/lb. High cost is due in part to the rather low heavy-mineral content of the placer alluvium, in part to the low ThO_2 content of the monazite, and in part to the relatively small size of these placers. Heavy minerals of these six placers make up only 0.10 to 0.33 percent of the placer material, and the average ThO_2 content of four analyses made on monazite from the Boise Basin is 3.2 percent (Kline and others, 1950, p. 32).

ELK CITY-NEWSOME AREA

The placers of the Elk City-Newsome area lie along the drainage of the upper South Fork of the Clearwater River in Idaho County (Reid, 1960); for the most part they occur along the tributaries emptying into this river. Placers in this area that have been evaluated for their monazite content are (1) Big and Little Elk Creeks, (2) American River, (3) Red Horse Creek, (4) Red River, (5) Crooked River, and (6) Newsome Creek. Most lie within 5 miles of Elk City, although Newsome Creek is about 10 miles from this town. The depth of the alluvium that makes up these placers is generally about 6–10 feet. The upper part of it is generally silt and the lower part, gravel. The latter contains some boulders over 10 inches across (Reid, 1960, p. 6–7). Dredging for gold has occurred along these streams. The average heavy-mineral content of the above-noted six placers ranges from about 0.4 to 1.3 percent of the placer sediments (Reid, 1960, p. 14–15; Storch and Holt, 1963, p. 63). Although the amount of heavy minerals compares favorably with that of placers in Long Valley, monazite makes up a much smaller percentage of the heavy minerals, ranging from about 0.35 to 1.8 percent. The principal heavy minerals in these placers are magnetite and ilmenite. Together they make up more than 90 percent of the heavy minerals in each of the placers. Garnet and zircon are also found in these placers. Zircon is about as abundant as monazite, and garnet about twice as common. The ThO_2 content of the monazite is low, about 2.7 percent (Overstreet, 1967, p. 149).

The six placers evaluated have reserves totaling 177 short tons of ThO_2 in 6,540 tons of monazite. Reserves range in size from 1.4 tons of ThO_2 on Red Horse Creek to 79 tons on Red River. In addition to monazite, these placers contain 124,000 tons of ilmenite, 7,180 tons of zircon, and 14,100 tons of garnet. The placers are shallow and do not have any underlying probable potential resources.

The cost of producing ThO_2 from any of the six placers, even with the aid of byproducts, would be greater than $50/lb. High cost is due to low monazite content of the heavy minerals and low ThO_2 content of the monazite.

VEINS AND PIPES IN THE BOKAN MOUNTAIN DISTRICT, ALASKA

The Bokan Mountain district surrounds the mountain of this name in the southern part of Prince of Wales Island in the southern part of the Alaskan panhandle. Bokan Mountain is about 40 miles southwest of Ketchikan, the nearest town. The district lies between the head of the West Arm of Kendrick Bay on the east and the South Arm of Moira Sound on the northeast. These two waterways afford access by boat within a few miles of most prospects. Thorium is associated with uranium and rare earths in veins, pegmatites, and a few irregular pipelike bodies. These deposits occur in and adjacent to the Bokan Mountain Granite, which underlies Bokan Mountain in a crudely circular area of a little over 3 square miles. This granite is a sodium-rich, riebeckite- and acmite-bearing rock with accessory zircon, fluorite, and thorite. It was intruded in Late Triassic or Early Jurassic time (Lanphere and others, 1964, p. 707), principally into quartz monzonite and quartz diorite of Ordovician age (Lanphere and others, 1964, p. 707). In addition, older metavolcanic rocks lie to the northwest of Bokan Mountain, and black slate interlayered with some phyllite, metasiltite, and impure quartzite forms a semicircular band around part of the Bokan Mountain Granite (MacKevett, 1963, pl. 1).

MacKevett (1963, pl. 1) showed 26 prospects containing uranium that lie within the Bokan Mountain Granite and another 14 in the surrounding rocks within 1.5 miles of this body. Since this early work several other prospects have been found. Short, irregular, granitic pegmatite lenses and dikes occur within the Bokan Mountain Granite (MacKevett, 1963, pl. 1). Some of these bodies contain thorium and uranium minerals, which are commonly concentrated in small pockets. Other parts of these pegmatites, as well as some entire pegmatites, are not abnormally radioactive. Because of the small size and erratic distribution of thorium and uranium values within these bodies, they are not considered a potential resource of either of these two metals.

The greater part of the thorium and uranium occurs in veins and pipes. A pipe on the Cub claims (Ross-Adams mine) was the source of the only uranium produced in Alaska. Approximately 94,000 short tons of high-grade uranium ore, containing about 1 percent U_3O_8 as well as substantial amounts of ThO_2, was produced from this orebody during three separate periods of production (Stephens, 1971, p. 152, 158). Known pipes are confined to the vicinity of the old Ross-Adams mine on the Cub property. The pipe that was mined here had an irregular plunge to the south. Its upper part had a shallow dip and was first mined from a broad trench some 300 feet long (Eakins, 1970, p. 14). At the south end of this trench the pipe plunged steeply and was traced another 670 feet during mining (Eakins, 1970, p. 13; Stephens, 1971, p. 157). Its cross section in this trench was reported by MacKevett (1963, p. 63–64) to be about 40 by 50 feet. The ore in the upper trench contained more than 0.5 percent U_3O_8, and a large part of the high-grade ore had about 1 percent U_3O_8 (MacKevett, 1963, p. 67). This ore generally contains slightly more thorium than uranium, but in a few places the thorium-to-uranium ratio is as much as seven to one. Texturally this ore resembles the granitic host rock, and most of the uranium and thorium minerals are scattered through the granitic host rock, although some mineralization is found along veinlets in the rock. Thorian uraninite and thorite are the principal primary uranium and thorium minerals. A little brannerite occurs locally. The principal gangue minerals are albite, quartz, and acmite. Accessory minerals include hematite, pyrite, galena, fluorite, zircon, sphalerite, and magnetite.

Veins are more widely scattered over an area of at least 18 miles and are found on all sides of Bokan Mountain. The larger and better explored veins lie along the mountain's southeast flank. The best known group, which consists of a number of parallel and subparallel veins that can be traced for 1.6 miles, belong to the I and L system (Staatz, 1978). Exposures are generally poor, and heavy soil cover and thick vegetation make tracing individual veins difficult. Veins in this area tend to be thin and commonly pinch out in short distances. Exposed vein lengths range from about 6 to 2,100 feet. The longest vein is part of the I and L vein system and occurs near the southwest end of this system. Veins range in thickness from about a quarter of an inch to 10 feet; most, however, are less than 1 foot thick. Numerous fractures cut the Bokan Mountain Granite and adjacent rocks. These fractures strike in several directions, but the most common and the longest fractures have a northwest strike. Veins are intruded along these fractures, and although they strike in several directions, most of them have a northwest strike. Dips are generally steep.

Mineral content may be highly variable even along the same vein. Quartz and albite are the principal gangue minerals. The principal thorium mineral is thorite, and the principal uranium mineral is thorian uraninite. These two elements also occur locally in allanite and brannerite. Rare earths are fairly abundant and occur principally in bastnaesite and xenotime. Less commonly they are found in synchisite, monazite, and allanite. Iron oxides are plentiful in some parts of the veins. They consist chiefly of goethite and hematite; minor amounts of magnetite are also present in many veins. Zircon, pyrite, and fluorite are found in many samples. In addition, some veins locally contain a little sphalerite, galena, rutile, phenacite, pyrochlore, and columbite. Uranium-rich areas can be identified in some places by the presence of thin coatings of secondary yellow uranium minerals, such as sklodowskite or kasolite, along fractures. Some veins are crudely zoned. In the I and L vein system, uraninite and xenotime occur mostly in the northwest part of the system and allanite in the southeastern part (Staatz, 1978, p. 518–519).

The ThO_2 content of the veins in the Bokan Mountain area is known from 44 samples. The values range from 0.0038 to greater than 11 percent. Individual analyses have been previously published on about two-thirds of these samples (MacKevett, 1963, p. 77; Staatz, 1978, p. 518–519). Some veins vary considerably in ThO_2 content from place to place, and nine samples from the longest vein in the I and L system ranged from 0.11 to greater than 11 percent ThO_2 (Staatz, 1978, p. 518–519). Although the ThO_2 content of individual parts of different veins may vary widely, particular veins, as a whole, tend to contain either small or large amounts of ThO_2.

The U_3O_8 content of 48 samples varies from 0.0033 to 3.3 percent and the thorium-to-uranium ratios of these samples range from 0.046 to 276. The thorium-to-uranium ratios of most samples fall in the range from 0.10 to 24. Some veins, such as the Wennie on the west side of Bokan Mountain, are characterized by high thorium-to-uranium ratios; others, like a group of small veins lying adjacent to the I and L vein system on the Atom Marietta claims, have low thorium-to-uranium ratios. These veins have some of the highest U_3O_8 content of all the veins analyzed. In some veins, however, the thorium-to-uranium ratio varies from place to place. This ratio ranged from 0.20 to 80 in the nine samples collected on the longest vein in the I and L system.

The total rare-earth-oxide content of 23 analyzed vein samples ranged from 0.05 to 13 percent. Individual analyses from eight different veins contain more than 1 percent total rare-earth oxides. Overall the total rare-earth oxides are about 2.5 times more abundant than the ThO_2. No apparent relationship exists, however, between the amount of one in a particular sample and the amount of the other, and the total ratio of rare-earth oxides to ThO_2 varies from 0.21 to 570. Veins on the west side of Bokan Mountain and in the southeast part of the I and L system tend to be proportionally rich in rare earths compared to thorium.

The relative amounts of lanthanides vary from sample to sample. In most other districts the amount of lighter rare earths (atomic numbers 57 to 64) greatly exceeds the amount of heavier rare earths. In the Bokan Mountain district, however, some samples are principally heavy rare earths, some have similar amounts of heavy and light rare earths, and some are principally light rare earths. This erratic rare-earth distribution occurs not only between veins but also within veins. The Bokan Mountain veins contain more heavy rare earths than most other rare-earth-bearing deposits.

Many veins and pipelike bodies were too poorly exposed or sampled to use in 1978 in making meaningful resource calculations. These calculations were made on veins as thin as 0.2 of a foot and include 16 veins and pipes. The resources are divided into reserves and probable potential resources. The reserves of a vein are calculated in the following manner: known length times average thickness times a depth equal to one-third the known length. The reserves of a pipe are the average cross-sectional area times the known length measured along its plunge. Probable potential resources are extensions of the reserves both laterally and at depth. For probable potential resources, the vein or pipe was extended a quarter of the known length in each direction.

This distance was shortened when rock exposures indicated that the vein had either pinched out or been faulted off. In veins the thickness used is the same as that used in calculating reserves, and the depth is one and a half times the trace of the vein, or half again as deep as the depth used for calculating the reserves. In pipes the length was multiplied by the average cross-sectional area used in calculating reserves. A tonnage factor of 12 cubic feet per short ton was used in converting volume to weight.

The total reserves and probable potential resources of ThO_2 in the 16 veins and pipes vary widely and range from less than 0.1 to about 1,600 tons of ThO_2. Total known reserves for this district are 1,440 short tons of ThO_2; total probable potential resources are 2,320 tons of ThO_2. Together they add up to 3,760 short tons of ThO_2. The average grade of ThO_2 in these deposits ranges from 0.012 to 1.44 percent, but 99 percent of these resources come from deposits whose grade is at least 0.2 percent ThO_2.

These veins and pipes also have reserves of U_3O_8 of 420 short tons; the probable potential resources for this U_3O_8 are 820 tons. Together they add up to 1,240 short tons of U_3O_8. The average grade of U_3O_8 in these deposits ranges from 0.016 to 1.3 percent; most of these resources come from deposits whose grade ranges from 0.06 to 0.55 percent U_3O_8.

The Bokan Mountain district also has resources of rare earths. Some of the smaller deposits have not been analyzed for rare earths. Grade data are available on 10 deposits, which contain 98 percent of the total rock that makes up all the resources. These deposits contain 9,320 short tons of total rare-earth oxides in reserves and 9,370 tons of total rare-earth oxides in probable potential resources. The average grade of these 10 deposits ranges from 0.16 to 8.9 percent total rare-earth oxides, but 90 percent of these resources comes from deposits whose grade is at least 2.0 percent total rare-earth oxides. Heavy rare earths are much more abundant in these deposits than in most deposits in other areas. Yttria (Y_2O_3) makes up 24 percent of the total rare-earth oxides in our samples. Reserves of yttria in these veins and pipes total 3,130 short tons and probable potential resources, 2,350 tons.

In addition to calculating total thorium resources, as above, the reserves and probable potential resources are divided into those that can be produced at three sets of costs: (1) those that can be produced at less than \$15/lb of ThO_2, (2) those that can be produced at between \$15 and \$30/lb, and (3) those that can be produced at between \$30 and \$50/lb. To obtain a basis for calculating these costs, J. F. Lemons, Jr., L. V. Coppa, and B. V. Clingan of the U.S. Bureau of Mines made cost analyses for both mine and mill models (Staatz and others, 1979; Lemons and Coppa, 1979, p. 3–25). The mine model used for making cost calculations is the cut-and-fill mining system, which was chosen because of its advantages of flexibility, grade control, and ground support. This method is designed to use mill tailings as backfill. Mine recovery of the ore is assumed to be 90 percent. Although the resources of all veins or pipes over a certain minimum thickness are included in the total reserve and resource calculations, some deposits do not contain enough ore to be economically mined. For purposes of the present calculations, deposits containing less than 35,000 short tons of minable ore are considered uneconomic and are not included in the resources producible at various costs. The type of mill visualized for recovering thorium in the Bokan Mountain district is one using acid-leach solvent-extraction techniques. The calculations assume that one hypothetical mill would be located by a stream near the head of the West Arm of Kendrick Bay. The cost of the mill would vary, depending on whether or not it also has circuits for recovering uranium and rare earths. To simplify procedures the cost divisions are calculated assuming that only thorium will be recovered. A description of the mining and milling method, as well as a discussion of various costs is given in Staatz and others (1979).

Cost calculations were made on the seven veins or pipes that were large enough to support an operating mine. Three of these deposits could produce ThO_2 at less than \$15/lb, one at between \$30 and \$50/lb, and the rest at more than \$50/lb. A total of 3,070 short tons of ThO_2 is producible at less than \$15/lb. This total can be divided into 1,180 tons of ThO_2 in reserves and 1,890 tons in probable potential resources. In addition to ThO_2, the ore contains 300 short tons of U_3O_8 in reserves and 575 tons of U_3O_8 in probable potential resources. This product would be obtained from 571,000 tons of ore having an average grade of 0.54 percent ThO_2 and 0.15 percent U_3O_8. Another 370 short tons of ThO_2 is producible at between \$30 and \$50/lb. This total can be divided into 80 tons of ThO_2 in reserves and 290 tons in probable potential resources. This ore also has reserves of 35 tons of U_3O_8 and probable potential resources of 125 tons of U_3O_8. This product is obtained from 49,000 tons of ore having an average grade of 0.76 percent ThO_2 and 0.33 percent U_3O_8. If the value of the U_3O_8 is taken into account in the deposit that could produce ThO_2 at between \$30 and \$50/lb, then the ThO_2 would be producible at between \$15 and \$30/lb.

CARBONATITE DIKES

GENERAL

Carbonatite dikes in the United States, like carbonatites around the world, typically contain a suite of rather exotic minerals and elements. They have been investigated at various times as potential sources of thorium, uranium, rare-earth elements, niobium, phosphate, and agricultural lime. Carbonatite dikes have been reported from many areas, but in most only one or two small dikes are known. This report covers six of the better known districts in which a number of carbonatite dikes have been reported. They are (1) the Powderhorn district, Colorado; (2) Mountain Pass, Calif.; (3) the Wet Mountains, Colo.; (4) Bearpaw Mountains, Mont.; (5) Ravalli County, Mont.-Lemhi County, Idaho; and (6) Magnet Cove and Potash Sulfur Springs, Ark. Carbonatite dikes are mainly tabular bodies, although small, irregular bodies in Arkansas have been included in this paper. Carbonatite dikes are from a few to several thousand feet in length and from a fraction of an inch to 150 feet thick. Individual dikes commonly vary in thickness along their strike. The principal mineral is a carbonate, generally calcite, although dolomite and siderite predominate in a few dikes. Over 50 different minerals have been identified in the carbonatite dikes described. Minerals common, although not necessarily plentiful, in many of those carbonatite districts include biotite, pyrite, potassium feldspar, quartz, fluorite, apatite, pyrrhotite, barite, pyrochlore, galena, and sphalerite. Thorium and (or) rare-earth minerals include thorite, monazite, bastnaesite, allanite, synchisite, ancylite, xenotime, parisite, and thorianite. Rarely do more than two of the thorium or rare-earth minerals occur in a single carbonatite. Carbonatites invariably contain considerably greater amounts of rare earths than they do thorium. They also may contain economically interesting amounts of Nb_2O_5 in pyrochlore or columbite.

The thorium resources for each district are reported in two ways: (1) total resources of all the carbonatites, and (2) resources that can be produced at three sets of costs. The first category is divided into reserves and probable potential resources. Reserves are those resources that are in part directly measured and sampled. Reserves of the carbonatite dikes are calculated in the following manner: known length of the dike times average thickness times a depth equal to one-third the length. Probable potential resources are extensions of the reserves both laterally and at depth, and they form a block of ore that surrounds the reserves. To estimate the probable potential resources, the carbonatite dike was assumed to extend on the surface one-quarter of the known length in each direction. This distance was shortened when rock exposures indicated that the dike either pinched out or ended by faulting. The same average dike thickness was used as in calculating the reserves. The depth of the probable-potential-resources block is assumed to be one-half times the trace of the dike. The resources of the shorter carbonatite dikes are not included in the overall resource calculation because the total amount of resources of dikes having a length of less than 100 feet is insignificant when compared to the total resources of all carbonatite dikes. A tonnage factor of 11.4 cubic feet per short ton (cu ft/short ton) is used in converting dike volume to dike weight.

Although six well-known districts are discussed, resources of three districts—Bearpaw Mountains, Mont.; Magnet Cove-Potash Sulphur Springs, Ark.; and Ravalli County, Mont.-Lemhi County, Idaho—are not evaluated. The ThO_2 content of the carbonatites in these three districts is so low that no significant resources would be found, nor could the ThO_2 be recovered at a cost of \$50/lb. Total reserves and probable potential resources of ThO_2 in carbonatite dikes in the Wet Mountains, Colo.; Mountain Pass district, California, and Powderhorn district, Colorado, total 6,450 short tons (table 8). These are divisible into 978 tons of reserves and 5,480 tons of probable potential resources. The average grade of these carbonatites ranges from 0.0015 to 1.07 per-

TABLE 8.—*ThO_2 reserves and probable potential resources, in short tons, of carbonatite dikes in three districts*

District	Reserves	Probable potential resources	Total producible at less than \$15/lb		Total producible at between \$15 and \$30/lb	
			Reserves	Probable potential resources	Reserves	Probable potential resources
Powderhorn, Colo	763	4,240	248	1,430	390	2,250
Mountain Pass, Calif	84	486	84	486	0	0
Wet Mountains, Colo	131	753	0	0	92	531
Total	978	5,479	332	1,916	482	2,781

cent ThO_2. The highest grade carbonatites occur in the Mountain Pass district.

The resources of ThO_2 are also divided into those reserves and probable potential resources that can be produced at less than \$15/lb of ThO_2, those that can be produced at between \$15 and \$30/lb, and those that can be produced at between \$30 and \$50/lb. To obtain a basis for calculating these costs, J. F. Lemons, Jr., L. V. Coppa, and B. V. Clingan of the U.S. Bureau of Mines made cost analyses for both mine and mill models (Staatz and others, 1979). The mine model used for making cost calculations is the cut-and-fill mining system; it is similar to that described in the section on Bokan Mountain veins and pipes.

Milling of carbonatite ore in various districts might vary somewhat depending on possible byproduct or coproducts recovered. Total rare-earth-oxide content in many samples is greatly in excess of the ThO_2 content, and in the carbonatite dikes evaluated, the average total rare-earth-oxide content is from 4 to 270 times more abundant than the ThO_2 content. Rare-earth recovery is taken into account in evaluating these rocks. In the Mountain Pass district, a mill for recovery of the rare earths from the massive carbonatite already exists. The separation of thorium from carbonatite dikes would only require an added circuit. These carbonatite dikes are primarily rare-earth deposits. If the value of rare is considered at 1978 prices, then the reserves of 332 short tons of ThO_2 could be produced at less than \$15/lb, and 482 tons of ThO_2 could be produced at between \$15 and \$30/lb; the cost of producing the remainder of the ThO_2 would be greater than \$50/lb (table 7). The amounts of probable potential resources in the same price range would be 1,920 tons of ThO_2 at a cost of less than \$15/lb and 2,780 tons of ThO_2 at a cost of between \$15 and \$30/lb. Although the production of much of the ThO_2 is dependent on having a sizable rare-earth byproduct, some of the ThO_2 could be produced without a rare-earth byproduct. If ThO_2 were the only product, then reserves of 296 tons of ThO_2 could be produced at less than \$15/lb, 174 tons of ThO_2 could be produced at between \$15 and \$30/lb, and 333 tons could be produced at between \$30 and \$50/lb. The amounts of probable potential resources in the same price range would be 1,700 tons at a cost of less than \$15/lb, 1,000 tons of ThO_2 at a cost of between \$15 and \$30/lb, and 1,920 tons at a cost of between \$30 and \$50/lb. Over 80 percent of the reserves and probable potential resources could be produced at less than \$50/lb without considering the value of byproduct rare earths.

POWDERHORN DISTRICT, COLORADO

Carbonatite dikes are associated with alkalic rocks, including a large massive carbonatite at Iron Hill and thorium veins in the Powderhorn district, Gunnison County. Thorium resources in thorium veins, the massive carbonatite, and disseminated deposits in nearby granite bodies in this district have previously been described (Staatz and others, 1979).

The Powderhorn area is underlain largely by metasedimentary and metavolcanic rocks intruded by Precambrian granite and other igneous rocks. In late Precambrian or Early Cambrian time, about 570 million years ago, the Precambrian rocks were intruded by alkalic igneous rocks and carbonatite of the complex at Iron Hill and by slightly younger diabase dikes (Olson and others, 1977). The complex consists chiefly of pyroxenite, magnetite-ilmenite-perovskite segregations, uncompahgrite, ijolite, hybrid pyroxenite-syenite rocks, nepheline syenite, and carbonatite, listed oldest to youngest (Hedlund and Olson, 1961). The central part of the complex is made up of massive carbonatite. Rocks of the complex and surrounding area have been mapped in detail by Hedlund and Olson (1968, 1975) and Olson (1974).

Several hundred carbonatite dikes intruding mainly pyroxenite of the complex at Iron Hill and the adjoining Precambrian rocks have been mapped by Olson (1974) and Hedlund and Olson (1975). They radiate outward from the carbonatite stock at Iron Hill, but do not appear to intrude it. The carbonatite dikes are typically 3–5 feet thick but a maximum thickness of 150 feet has been noted. Some dikes can be traced discontinuously for 300–600 feet along strike. All carbonatite dikes recognized to date are found within 1 mile of the alkalic complex at Iron Hill. The distribution of minerals and their grain sizes tend to be fairly homogeneous, although breccia and mineral layering have been observed. The near-surface and surface exposures are various shades of brown, reddish brown, and yellowish brown because of the oxidation and hydration of iron-bearing minerals. According to J. C. Olson and D. C. Hedlund (written commun., 1978), the following minerals, in decreasing order of frequency of occurrence, are found in the carbonatite dikes: dolomite, calcite, siderite, biotite, phlogopite, pyrite (including goethite pseudomorphs after pyrite), barite, apatite, potassium feldspar, pyrochlore, monazite, chalcopyrite, sphalerite, galena, fluorite, synchisite, and parisite. Siderite occurs as distinct segregations in a few dikes, and these siderite-rich zones contain ralatively abundant pyrite and tend to be more radioactive than the portions of carbonatite that lack siderite. The pyrite may be partly or entirely replaced by geothite. The other sulfide minerals are sparse. No minerals that contain thorium as a major constituent have been found, although thorium most likely occurs in pyrochlore and monazite and perhaps in the other minerals that contain abundant rare-earth elements. The ThO_2 content of various carbonatite dikes ranges from about 0.0035 to 0.361 percent.

Resources were calculated for 13 carbonatite dikes that have an exposed length of from 150 to 1,200 feet. Reserves of these deposits total 763 short tons of ThO_2 and probable potential resources are estimated to be 4,240 tons. The total reserves and probable potential resources of individual carbonatite dikes range from 14 to 1,670 tons of ThO_2. In addition, these carbonatites also contain reserves of 21,000 tons of total rare-earth oxides, 1,330 tons of Nb_2O_5, and 57 tons of U_3O_8. Other probable potential resources in these carbonatites include 106,000 tons of total rare-earth oxides, 6,590 tons of Nb_2O_5, and 287 tons of U_3O_8. Twelve of the thirteen dikes were large enough to be considered in opening a mine. The cost of producing a pound of ThO_2 in one of these dikes was less then $15/lb. This carbonatite had reserves of 248 tons of ThO_2 and probable potential resources of 1,430 tons. The cost of producing a pound of ThO_2 in four other dikes was between $15 and $30/lb. These carbonatites had reserves of 390 tons of ThO_2 and probable potential resources of 2,250 tons. The cost of producing a pound of ThO_2 from all the other carbonatites is greater than $50/lb.

MOUNTAIN PASS, CALIFORNIA

Three types of thorium deposits occur in the Mountain Pass district, San Bernardino County, Calif.: carbonatite dikes, a massive carbonatite body (the Sulphide Queen body), and thorium veins. A mine on the Sulphide Queen carbonatite is the largest producer of rare earths in the United States. Both the massive carbonatite body and the thorium veins have been discussed previously (Staatz and others, 1979, p. 19–20 and 31–33). Carbonatite dikes at Mountain Pass are found chiefly in the Birthday area north and northwest of the Sulphide Queen massive carbonatite, just south of the transverse fault that defines the northern boundary of the area. Carbonatite dikes are also found at several other localities, such as the Simon-Ray prospect about 600 feet southeast of the Sulphide Queen stock.

The carbonatite dikes are associated with potassic igneous intrusive rocks. These rocks intrude a belt of Precambrian metamorphic and igneous rocks. The area including these carbonatites is bounded on the east and south by alluvium of Ivanpah Valley and on the west by the Clark Mountain fault. The north boundary is formed by a transverse fault that cuts the Clark Mountain fault (Olson and others, 1954, p. 4–8).

The carbonatite dikes range in thickness from less than 1 to about 20 feet and can be traced along strike for a maximum of about 400 feet. They characteristically contain abundant calcite and barite with or without abundant bastnaesite. Other minerals include siderite, quartz, fluorite, galena, pyrite, apatite, crocidolite, wulfenite, biotite, thorite, hematite, magnetite, goethite, and potassium feldspar. Calcite may form as much as 90 percent of some dikes and occurs as grains several tenths of an inch in diameter. Barite is usually pink or tan and may form as much as 30 percent of some dikes. Thorite, the principal source of thorium, is found in tiny reddish-brown crystals, commonly along fractures. Bastnaesite, which is the chief rare-earth mineral, occurs as tabular crystals as long as 4 inches and may form as much as 30 percent of the rock. The ThO_2 content of the carbonatite dikes varies from 0.024 to 2.39 percent (Olson and others, 1954, p. 68–69). These same dikes range in total rare-earth-oxide content from 2.03 to 18.64 percent. Some carbonatites are narrow and some are exposed in only one working. We have limited our resource calculations to carbonatites at least 3 feet in average thickness and at least 100 feet long for which analytical data are available. Five carbonatites fall in this category. Average thickness among these ranges from 3 to 10 feet.

The combined figures for reserves plus probable potential resources for each of these five carbonatites ranges from 65 to 220 short tons of ThO_2, and the total for all five deposits is 570 tons. Of this amount reserves make up 84 short tons and probable potential resources 486 tons. In addition, the reserves and probable potential resources would yield approximately 40 times as much total rare-earth oxides as ThO_2. Thorium would normally be produced here as a byproduct of the recovery of rare earths. All the reserves and probable potential resources could be produced at less than $15/lb. Although our calculations incorporate the cost of building a new mill, all that needs to be done to recover thorium in this area is to add a thorium circuit to the mill used in recovering rare earths.

WET MOUNTAINS AREA, COLORADO

Carbonatite dikes in the Wet Mountains area, Fremont and Custer Counties, can be divided into primary magmatic and replacement carbonatites (Armbrustmacher, 1979). Only the primary magmatic carbonatites have sufficiently high concentrations of thorium to be considered as a resource.

Carbonatite dikes in the Wet Mountains are spatially and genetically related to three alkalic intrusive complexes of Cambrian age (Olson and others, 1977): the Gem Park Complex (Parker and Sharp, 1970; Roden and Cullers, 1976), the McClure Mountain Complex (Shawe and Parker, 1967), and the complex at Democrat Creek (Heinrich and Dahlem, 1966). Precambrian host rocks of the alkalic complexes and carbonatites consist of Proterozoic X metamorphic rocks—primarily layered granitic gneisses, hornblende gneisses, and amphibolites—and Proterozoic X and Y intrusive granitic rocks of Boulder Creek age (1.72 b.y.) and Silver Plume age (1.45 b.y.) (Taylor and others, 1975a, b). The mafic-ultramafic parts of the McClure Mountain and Gem Park Complexes are similar to each other in nearly every respect. They consist chiefly of layered gabbro and pyroxenite, although rocks at Iron Mountain (McClure Mountain Complex) also include minor anorthosite, dunite, peridotite, and troctolite. In addition, the McClure Mountain Complex contains abundant biotite-hornblende syenite, nepheline syenite, and mafic nepheline-bearing rocks, whereas the Gem Park Complex contains leucocratic rocks—pegmatitic nepheline-and sodalite-bearing syenite—at only one locality. Mafic-ultramafic rocks also occur with the predominantly leucocratic complex at Democrat Creek. Carbonatite dikes intrude the alkalic complexes and their Precambrian host rocks. Thorium veins also occur in the vicinity of the alkalic intrusions and are probably genetically related to them (Armbrustmacher, 1976; Christman and others, 1959). The resources of the thorium viens have been reported (Staatz and others, 1979, p. 12–13).

Carbonatites in the Wet Mountains area form dikes that range in thickness from about 1 inch to 9 feet—a typical thickness is 3 feet. They are discontinuous along strike and are rarely traced along strike for a distance of more than several hundred feet, although one carbonatite has been traced for 1,400 feet. They tend to be quite coarse grained; carbonate grains as much as 2 inches across are common. Most carbonatite outcrops are brown, greenish brown, or, rarely, bluish gray on fresh surfaces. Unoxidized carbonatite from below the zone of oxidation is nearly white. All of the primary magmatic carbonatites thus far examined occur within 4 miles of one of the alkalic intrusive complexes. They are quite numerous west of the McClure Mountain Complex, east of the McClure Mountain complex along Bear Creek, and at Gem Park. Carbonatites west of the McClure Mountain Complex in the Road Gulch area have been discussed by Staatz and Conklin (1967), and the Goldie carbonatite has been described by Heinrich (1977). A total of 41 mineral species have been identified in the carbonatites, and they are listed in Armbrustmacher and Brownfield (1978). Calcite is ubiquitous, dolomite is very common, and strontianite and ankerite are sparse. Bastnaesite is a fairly common constituent and has been identified in nearly 50 percent of the samples studied. Quite commonly the bastnaesite is associated with synchisite and, rarely, with ancylite and strontianite. Other rare-earth-bearing minerals include monazite, xenotime, and fluorapatite. Quartz, hematite, and barite are common and are present in variable amounts; microcline is also quite common. Pyrite is more common than sphalerite or galena and its alteration product cerussite. Thorite, fluorite, and pyrochlore have also been identified in a few samples. A unique aluminofluoride mineral assemblage occurs in the Goldie carbonatite (Heinrich and Anderson, 1965; Heinrich and Quon, 1963; and Heinrich, 1977). The carbonatite dikes at Gem Park contain minerals that have not been identified in carbonatites elsewhere in the Wet Mountains area and include columbite, natrolite, pyrrhotite, and thorianite (Parker and Sharp, 1970).

Primary magmatic carbonatites in the Wet Mountains area contain an average of 0.17 percent ThO_2, 0.0097 percent Nb_2O_5, 0.0031 percent U_3O_8, and 2.15 percent total rare-earth oxides. Many of the carbonatites tend to be elongated, lens-shaped bodies that have a limited strike length. Resources were calculated on the seven largest carbonatite dikes, including the Klondike, Cabin, Dreamer's Hope, and Goldie. Total reserves in these deposits are 131 tons of ThO_2; total probable potential resources are 753 tons. The total reserves and probable potential resources of individual deposits range from 14 to 288 tons of ThO_2. In addition to ThO_2 the total reserves contain 2,500 tons of total rare-earth oxides, 17 tons of U_3O_8, and 40 tons of Nb_2O_5. The probable potential resources also contain 14,300 tons of total rare-earth oxides, 105 tons of U_3O_8, and 228 tons of Nb_2O_5. The cost of producing a pound of ThO_2 was less than $50/lb from only three of these dikes. These three dikes had reserves of 92 tons of ThO_2 and probable potential resources of 531 tons of ThO_2. ThO_2 could be recovered from these three dikes at between $15 and $30/lb.

BEARPAW MOUNTAINS, MONTANA

The Bearpaw Mountains represent an isolated mountain range of volcanic origin rising about 4,000 feet above the surrounding plains in north-central Montana. Carbonatites and other alkalic rocks, including the Rocky Boy stock, are found in the west end of these mountains. Carbonatites in the Bearpaw Mountains are associated with alkalic magmas that were intruded and extruded to form the Bearpaw volcanic field in early Tertiary time (Schmidt and others, 19?4). The largest and most complex alkalic body is the Rocky Boy stock, which is composed of four general rock groups, oldest to youngest: (1) biotite pyroxenite, (2) shonkinite, (3) monzonite, and (4) porphyritic potassic syenite (Pecora, 1962). Silicocarbonatite dikes and stockworks occupy fractures in this plug and the adjacent shonkinite and monzonite. The carbonatite dikes are fairly abundant in holes drilled by Texas Instruments Co. to assess the distribution of rare earths. Almost 20 percent of the core consisted of silicocarbonatite and sovitic carbonatite in intersect segments ranging from a few tenths of an inch to 50 feet thick (Pecora, 1962). The largest carbonatite dikes exposed on the surface exceed 40 feet in width. Much of the anomalous radioactivity in the core, however, does not occur in the carbonatites but is localized in altered potassic syenite and associated pegmatites.

The silicocarbonatites and sovitic carbonatites consist chiefly of calcite, orthoclase, biotite, pyrite, and pyrrhotite. Accessory minerals include aegirine, siderite, apatite, quartz, uranoan pyrochlore, barite, ilmenite, sphalerite, galena, zircon, burbankite, ancylite, calkinsite, strontianite, celestite, and lanthanite. The rare-earth carbonates burbankite and calkinsite were first described from this area (Pecora and Kerr, 1953). A wide variation in the distribution of essential and accessory minerals occurs between carbonatites. Thorium minerals have not been identified. Surface exposures of carbonatites, although not particularly abundant, are not especially radioactive. Analyses of five carbonatites, including the most radioactive one noted, contain from 4 to 60 ppm ThO_2. These rocks have an average of about 17 ppm ThO_2. The ThO_2 content of the carbonatite dikes, from the limited analytical information available, does not indicate either economic or near-economic amounts.

RAVALLI COUNTY, MONTANA-LEMHI COUNTY, IDAHO

A variety of carbonatite dikes is found in an area nearly 18 miles long by 4 miles wide that straddles the Montana-Idaho border across the Bitterroot Mountains. The southern part of this area is in the Mineral Hill mining district.

The carbonatite dikes are intruded chiefly into Precambrian metamorphic rocks. The dikes are tabular to lens-shaped and tend to either lie parallel to the foliation of their gneissic host rock or at a small angle to the foliation. The dikes are a few inches to about 10 feet thick. One of the more fully explored carbonatites can be traced for more than 300 feet; it ranges from 1 1/2 to 6 feet thick. Another carbonatite, as evidenced from scattered exposures, may be more than 1,000 feet long (Anderson, 1960, p. 1183). Byron Sharp and Donald Hetland, then of the U.S. Atomic Energy Commission, reported on another carbonatite that can be traced for 2,200 feet (written commun., 1968). Texturally the carbonatites range from fine to coarse grained. Their major constituents are calcite and dolomite; biotite, chlorite, actinolite, allanite, quartz, barite, apatite, monazite, pyrite, magnetite, ancylite, and columbite may be present in significant amounts locally. Additional minerals usually present in accessory amounts include pyrrhotite, chalcopyrite, molybdenite, hematite, rutile, crocidolite, niobium, rutile, ilmenite, fersmite, eschynite, fluorite, malachite, garnet, albite, muscovite, glaucophane, and wollastonite (Anderson, 1960, p. 1184; Heinrich and Levinson, 1961, p. 1429–1438).

Although several thorium-bearing minerals are fairly common in these carbonatites, their ThO_2 content tends to be low. Monazite from a carbonatite dike in the northern part of the area is reported by Heinrich and Levinson (1961, p. 1434) to contain 0.7 percent ThO_2, and allanite from the same dike, only a trace ThO_2.

Analytical data on the carbonatite dikes are sparse. Two samples cut across carbonatite dikes in the southern part of this area contained 0.089 and 0.0054 percent ThO_2. Sufficient data on size of the various carbonatite dikes are not available to make reliable estimates of their volume. As the average thickness of most of these dikes is between 1 and 2 feet and as their ThO_2 content is apparently low, the carbonatite dikes in this area do not appear favorable for significant ThO_2 resources.

MAGNET COVE AND POTASH SULFUR SPRINGS, ARKANSAS

Magnet Cove is in Hot Springs County, Ark., and Potash Sulfur Springs area is nearly 6 miles west of there in Garland County. Carbonatite dikes and small bodies form parts of alkalic igneous complexes at these two places. Economically significant deposits of rare-earth elements, barite, niobium, titanium, uranium, phosphate, agricultural lime, and vanadium have supplied the incentive for detailed studies of the geology (Erickson and Blade, 1963; Howard and Steele, 1975). Carbonatite bodies at Magnet Cove are part of a complex of alkalic rocks that form a well-differentiated ring-dike sequence (Johnson and Baker, 1976). These igneous rocks are intruded into complexly folded sedimentary rocks ranging from Silurian to Mississippian in age. Carbonatite dikes at Potash Sulfur Springs intrude alkalic rocks that have also been described as a ring-dike sequence (Howard and Steele, 1975). The alkalic complex at Potash Sulfur Springs is the site of the only mine operated for vanadium alone in the United States. Carbonatite dikes and irregularly shaped masses that occur in this area consist of coarse-grained sovitic carbonatite covered in part at Magnet Cove by residual phosphate-rich saprolite. Natural exposures are rare, and the best exposures occur at the Kimzey calcite quarry at Magnet Cove and at the Union Carbide Corp. open-pit vanadium mine at Potash Sulfur Springs. The carbonatite at Magnet Cove consists chiefly of seven primary minerals in the following order of decreasing abundance: calcite, apatite, monticellite, magnesium-rich magnetite, perovskite, phlogopite, and pyrite (Nesbitt and Kelly, 1977). The mineral kimzeyite, a zirconium garnet, was first described from carbonatite at the Kimzey calcite quarry (Milton and Blade, 1958). Other minerals include anatase, idocrase, anhydrite, humite, dolomite, molybdenite, biotite, and pyrrhotite. Minerals found in the carbonatite at Potash Sulfur Springs include calcite, aegirine-augite, andradite, pyrite, zircon, analcite, and biotite. The thorium, uranium, and rare-earth contents of carbonatites from Magnet Cove and Potash Sulfur Springs are low relative to carbonatites from other areas. At the outcrop the Arkansas carbonatites are not anomalously radioactive. According to Erickson and Blade (1963), thorium does not exceed about 34 ppm in all the rocks of the Magnet Cove Complex. Six samples of unweathered carbonatite taken from the two areas by us range from 0.65 to 24 ppm ThO_2. All except one sample, however, had less than 5 ppm ThO_2. The analyses available, as well as their low overall radioactivity, suggest that the amount of ThO_2 in the carbonatites is too small to represent even a subeconomic resource.

APATITE-BEARING IRON DEPOSITS OF MINEVILLE, NEW YORK

Thorium, rare earths, and a little uranium were found in 1952 in apatite from iron ores in the Mineville, N.Y., area (McKeown and Klemic, 1956, p. 9). The Mineville iron district is located in the northeastern part of the Adirondack Mountains along the west side of Lake Champlain. Most of the iron mines here are near the towns of Mineville and Port Henry in Essex County. There are several iron deposits in an area of approximately 30 square miles in this district. The main apatite-rich deposits are the Old Bed, Cheever, and Smith orebodies. The Cheever and Smith orebodies are mined out.

Iron-ore mining started at the Cheever mine in 1804 (Birkinbine, 1890, p. 747). In 1824 other mines were opened (J. R. Linney, 1943, p. 481). The district did well during the period between 1860 and 1890. Mining was severely curtailed in the next 10 years owing to the depressed state of the iron industry and expansion of mines in the Lake Superior district. The various holdings in the district were incorporated by Witherbee, Sherman, and Co., who developed the district into one of the more successful enterprises of its day (J. R. Linney, 1943, p. 481). This company bought land, did exploration, and opened new orebodies, such as Old Bed, Harmony, New Bed, Fisher Hill, and Sherman. During World War I this company was an important contributor to this country's supply of iron. Changes in the industry following this war caused the company to have financial setbacks, and in 1938 the company's holdings were leased to Republic Steel Corp. Republic Steel replaced worn-out equipment and increased the amount of ore shipped to the blast furnaces from 500,000 to 1,000,000 long tons per year by 1942 (R. J. Linney, 1943, p. 488). Since then, some of the deposits have been worked out, and Republic Steel Corp. closed their operation in 1970.

The iron deposits are divided according to their phosphorus content into high- and low-phosphorus deposits, or into Bessemer and non-Bessemer grades (R. J. Linney, 1943, p. 488). Separate mills were set up to separate iron from each of these types of deposits. High-phosphorus ores are those containing more than 0.5 percent phosphorus in the ore. The Old Bed orebody, which averaged 1–1.25 percent phosphorus, furnished the greater part of the Bessemer-type ore (R. J. Linney, 1943, p. 489). This amount of phosphorus would be equivalent to about 6–7.2 percent apatite. As the thorium is principally in the apatite, the principal phosphorus-bearing mineral in the ore, the low-phosphorus ores contain little thorium.

The rocks in the area of the magnetite deposits form a complex suite of metamorphic and igneous rocks of Precambrian age (Kemp and Ruedemann, 1910; Newland, 1908). Granite, gabbro, syenite, gneiss, and diorite are the principal rock types and, in most places, the host rocks for the iron deposits. Extensive folding and faulting have resulted in a complex structure. The iron deposits are made up principally of magnetite, martite, and apatite. Gangue minerals include augite, hornblende, albite, quartz, pyrite, and tourmaline (McKeown and Klemic, 1956, p. 14).

Except in ore that is almost entirely magnetite, no obvious relationship exists between the amount of magnetite and the amount of apatite;

apatite is generally present in the Old Bed ore. Apatite occurs in slightly distorted rice-shaped grains about 1–3 mm long. The apatites vary in color and may be reddish brown, green, white, or transparent. The reddish-brown apatite is by far the most common variety. The rare-earth content of the apatites, and presumably the thorium content, varies considerably. The reddish-brown apatite contains between 5.8 and 20.6 percent total rare earths, the green variety between 0.5 and 2.0 percent, and the white and transparent varieties only trace amounts. Microscopic examination of the reddish-brown apatite indicated that the color is due to mineral inclusions and coatings (McKeown and Klemic, 1956, p. 12). X-ray diffraction patterns of reddish-brown material left after the apatite was leached away by acid showed it to be monazite, bastnaesite, and hematite. In addition to rare earths, the apatite contains thorium and uranium. Analyses made on 14 samples of apatites separated from the Old Bed, Joker, and Smith orebodies had an average ThO_2 content of 0.17 percent and an average U_3O_8 content of 0.038 percent (McKeown and Klemic, 1956, p. 15).

Apatite occurs in 1978 both in large tailings dumps from previous operations and in unmined portions of various magnetite orebodies. The amount of ore in unmined bodies is not known. As sufficient data are not presently available to assess possible resources in unworked parts of various mines, the rest of this paper is confined to the more readily available thorium and uranium resources in the tailings dumps. Furthermore, the cost of recovering apatite from the dumps is much less, as it is already mined, ground, and partially sorted.

Tailings piles include material derived from both the high- and low-phosphorus deposits (or apatite-rich and apatite-poor deposits). Some piles are mixtures of both types of ore. The low- and high-phosphorus ores were partly divided from the early 1900's, when separate mills were set up to handle the different types of ores. Tailings piles made up primarily of low-phosphorus iron ore are not important as sources of thorium. The Old Bed deposit was the largest and most extensively worked apatite-rich deposit in the district. In addition, the Old Bed mill also handled ore from adjacent apatite-poor deposits. Other tailings piles that have received some apatite-rich ore are adjacent to the no. 6, no. 7, and Cheever mills. The old no. 6 mill was at Port Henry on Lake Champlain. This mill handled some low-grade apatite ores, although the greater part of the operation involved apatite-rich ores. This tailings pile extends out into Lake Champlain. The no. 7 mill tailings pile, about a mile east of Moriah Center, is the largest in the district. Although this mill has treated both apatite-rich and apatite-poor iron ores, approximately two-thirds of the tailings pile came from apatite-rich orebodies. The Cheever mine and tailings dump is about 21 miles north of Port Henry on the west side of Lake Champlain. In addition to these tailings piles, there is a small dump containing partially concentrated apatite, which lies approximately 500 feet northwest of the Old Bed tailings pile. This concentrate was made at the no. 5 mill, which was built to recover apatite for fertilizer before it burned down.

Dumps in the Mineville district are estimated to have about 18,000,000 short tons of tailings. Approximately two-thirds, or at least 10,000,000 tons, of these tailings was derived from apatite-rich iron ores. The amount of apatite in the tailings from the apatite-rich dumps was calculated from data given by McKeown and Klemic (1956, p. 21–22). These figures indicated that 8 percent of the tailings is apatite, or that approximately 800,000 short tons of apatite occurs in the dumps. The average apatite contains about 0.17 percent ThO_2 and 0.038 percent U_3O_8 (McKeown and Klemic, 1956, p. 15). The amount of apatite in the dumps would contain 1,360 short tons of ThO_2 and 304 tons of U_3O_8. In addition, the apatite is rich in rare earths, and McKeown and Klemic (1956, p. 15) reported that 12 specimens had an average rare-earth-oxide content of 13 percent. Thus, the dumps would also contain 104,000 short tons of total rare-earth oxides. Spectrographic analyses given by McKeown and Klemic (1956, p. 12) indicated that yttrium is one of the principal rare earths. Hence, these tailings are also a potential source for the yttrium-group rare earths.

The cost of milling the tailing piles has not been calculated. The possible economic products of the apatite from the Mineville area are thorium, uranium, total rare-earth oxides, yttrium oxide, and phosphoric acid. The cost of milling the tailings under various conditions can be calculated. If only thorium and uranium were recovered and they could be sold for \$30/lb, then the value of the thorium and uranium per ton of tailings would be about $10. Rare earths and phosphorus, however, would undoubtedly play an important part in any economic recovery of thorium and uranium. In 1978 total rare-earth oxides were selling for about $0.60/lb and Y_2O_3, about $7/lb. The value of the total rare-earth oxides would be equivalent to $12.48/ton of tailings, if a market could be found for this amount of rare earths at 1978 prices. If Y_2O_3 made up 10 percent or more of the total rare earths, then the added value due to the Y_2O_3 would more than double the value due to rare earths in a ton of tailings. Because the apatite would be taken into solution to recover the thorium, coproducts of uranium, rare earths, and phosphorus could be cheaply produced.

The above figures suggest that thorium and uranium could be recovered at a cost between $15 and $30/lb without the aid of any other product; with the development of a rare-earth market they could probably be produced at less than $15/lb.

REFERENCES CITED

Anderson, A. L., 1960, Genetic aspects of the monazite and columbium-bearing rutile deposits in northern Lemhi County, Idaho: Economic Geology, v. 55, p. 1179–1201.

Alt, D., and Brooks, H. K., 1965, Age of the Florida massive terraces: Journal of Geology, v. 73, p. 406–411.

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

Armbrustmacher, T. J., 1976, Thorium deposits in the Wet Mountains area, Fremont and Custer Counties, Colorado: U.S. Geological Survey Open-File Report 76–384, 18 p.

______1979, Replacement and primary magmatic carbonatites from the Wet Mountains area, Fremont and Custer Counties, Colorado: Economic Geology, v. 74, no. 4, p. 888–901.

Armbrustmacher, T. J., and Brownfield, I. K., 1978, Carbonatites in the Wet Mountains area, Custer and Fremont Counties, Colorado—Analytical and mineralogical data: U.S. Geological Survey Open-File Report 78-177, 6 p.

Armstrong, F. C., 1955, The Dismal Swamp placer deposit, Elmore County, Idaho: U.S. Geological Survey Trace Elements Memorandum Report 298, 24 p.

Berggen, W. A., and Van Couvering, J. A., 1974, The late Neogene—Biostratigraphy, geochronology, and paleoclimatology of the last 15 million years in marine and continental sequences: Paleogeography, Paleoclimatology, and Paleoecology, v. 16, p. 1–216.

Birkinbine, John, 1890, Crystalline magnetite in the Port Henry, New York mines: Transactions of the American Institute of Mining Engineers, v. 18, p. 747–762.

Calver, J. L., 1957, Mining and mineral resources: Florida Geological Survey Bulletin 39, 132 p.

Capps, S. R., 1940, Gold placers of the Secesh Basin, Idaho County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 52, 42 p.

Carpenter, J. H., Detweiler, J. C., Jr., Gillson, J. L., Weichel, E. C., Jr., and Wood, J. P., 1953, Mining and concentration of ilmenite and associated minerals at Trail Ridge, Fla.: Mining Engineering, v. 5, no. 8, p. 789–795.

Christman, R. A., Brock, M. R., Pearson, R. C., and Singewald, Q. D., 1959, Geology and thorium deposits of the Wet Mountains, Colorado—A progress report: U.S. Geological Survey Bulletin 1072-H, p. 491–535.

Clark, W. B., and Miller, B. L., 1912, The physiography and geology of the coastal plain province of Virginia: Virginia Geological Survey Bulletin 4, 274 p.

Cooke, W. C., 1931, Seven coastal terraces in the southeastern states: Washington Academy of Sciences Journal, v. 21, p. 503–513.

______1932, Tentative correlation of American glacial chronology and the marine time scale: Washington Academy of Sciences Journal, v. 22, p. 310–313.

Daily, A. F., 1968, Dredges and hydraulicking, *in* Pfleider, E. P., ed., Surface mining: American Institute of Mining, Metallurgical and Petroleum Engineers, Seeley W. Mudd Series, p. 503–527.

Doering, J. A., 1960, Quaternary surface formations of southern part of Atlantic Coastal plain: Journal of Geology, v. 68, p. 182–202.

Eakins, G. R., 1970, An experiment in geobotanical prospecting for uranium, Bokan Mountain area, southeastern Alaska: Alaska Department of Natural Resources, Division of Mines and Geology, Geologic Report 41, 52 p.

Eilertsen, D. E., and Lamb, F. D. 1956, A comprehensive report of exploration by the Bureau of Mines for thorium and radioactive black mineral deposits: U.S. Atomic Energy Commission RME–140, 45 p.

Erickson, R. L., and Blade, L. V., 1963, Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas: U.S. Geological Survey Professional Paper 425, 95 p.

Garnar, T. E., Jr., 1972, Economic geology of Florida heavy mineral deposits, *in* Puri, H. S., ed., Geology of Industrial Minerals, 7th Forum: Proceedings Florida Bureau of Geology Special Publication 17, p. 17–21.

Gunter, Herman, 1955, Eleventh biennial report of the Florida Geological Survey covering period of January 1, 1953 through December 31, 1954: Florida Geological Survey, p. 3–60.

Hedlund, D. C., and Olson, J. C., 1961, Four environments of thorium-, niobium-, and rare-earth-bearing minerals in the Powderhorn District of southwestern Colorado, *in* Short papers in the geologic and hydrologic sciences: U.S. Geological Survey Professional Paper 424–B, p. B283–B286.

______1968, Geologic map of the complex of alkalic rocks at Iron Hill, Gunnison County, Colorado: U.S. Geological Survey Open-file map.

______1975, Geologic map of the Powderhorn quadrangle, Gunnison and Saguache Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ–1178.

Heinrich, E. W., 1977, Aluminofluoride minerals of the Goldie carbonatite, Fremont County, Colorado: Mountain Geologist, v. 14, p. 33–46.

Heinrich, E. W., and Anderson, R. J., 1965, Carbonatites and alkalic rocks of the Arkansas River area, Fremont County, Colorado. 2, Fetid gas from carbonatite and related rocks: American Mineralogist, v. 50, p. 1914–1920.

Heinrich, E. W., and Dahlem, D, H., 1966, Carbonatites and alkalic rocks of the Arkansas River area, Fremont County, Colorado, *in* Naidu, P. R. J., ed., IMA volume: Mineralogical Society of India, p. 37–44.

Heinrich, E. W., and Levinson, A. A., 1961, Carbonatic niobium-rare earth deposits, Ravalli County, Montana: American Mineralogist, v. 46, p. 1424–1447.

Heinrich, E. W., and Quon, S. H., 1963, New type of deposit of aluminofluoride minerals from Fremont County, Colorado [abs.]: Geological Society of America Special Paper 73, p. 169.

Howard, J. M., and Steele, K. F., 1975, Origin of the Potash Sulfur Springs Intrusive Complex, Arkansas: Geological Society of America Abstracts with Programs, v. 7, no. 1, p. 502.

Johnson, M. L., and Baker, D. R., 1976, Intrusive model of the Magnet Cove Complex, Arkansas: Geological Society of America Abstracts with Programs, v. 8, no. 1, p. 26.

Kauffman, A. J., Jr., and Baber, K. D., 1956, Potential of heavy-mineral- bearing alluvial deposits in the Pacific Northwest: U.S. Bureau of Mines Information Circular 7767, 36 p.

Kemp, J. F., and Ruedemann, Rudolf, 1910, Geology of the Elizabethtown and Port Henry quadrangles, New York State Museum Bulletin 138, 173 p.

Kline, M. H., and Carlson, E. J., 1954, Pearsol Creek monazite placer area, Valley County, Idaho: U.S. Atomic Energy Commission RME-3134, 23 p.

Kline, M. H., Carlson, E. J., and Griffith, R. H., 1950, Boise Basin monazite placers, Boise County, Idaho: U.S. Atomic Energy Commission RME-3129, 37 p.

Kline, M. H., Carlson, E. J., and Horst, H. W., 1955, Corral Creek monazite placer area, Valley County, Idaho: U.S. Atomic Energy Commission RME-3135, 22 p.

Kline, M. H., Carlson, E. J., and Storch, R. H., 1951a, Big Creek monazite placers, Valley County, Idaho: U.S. Atomic Energy Commission RME-3131, 24 p.

______1951b, Scott Valley and Horsethief Basin monazite placers, Valley County, Idaho: U.S. Atomic Energy Commission RME-3133, 22 p.

Kline, M. H., Carlson, E. J., Storch, R. H., and Robertson, A. F., 1953, Bear Valley radioactive mineral placers, Valley County, Idaho: U.S. Atomic Energy Commission RME-3130, 22 p.

Kremers, H. E., 1958, Commercial thorium ores: Society of Mining Engineers of American Institute of Mining Engineers preprint 5819A18, p. 1–14.

Lanphere, M. A., MacKevett, E. M., Jr., and Stern, T. W. 1964, Potassium-argon and lead-alpha ages of plutonic rocks, Bokan Mountain, Alaska: Science, v. 145, no. 3633, p. 705–707.

Lemons, J. F., Jr., and Coppa, L. V., 1979, Mining and processing methods and cost models for the recovery of thorium from domestic occurrences: U.S. Department of Energy GJBX-91(79), 68 p.

Liddell, D. M., 1917, A Florida rare-mineral deposit: Engineering Mining Journal, v. 104, no. 4, p. 153–155.

Lindgren, Waldemar, 1897a, Monazite from Idaho: American Journal of Science, 4th ser., no. 19, p. 63–64.

______1897b, Monazite from Idaho: Mining and Scientific press, v. 75, p. 168.

Linney, J. R., 1943, A century and a half of development behind the Adirondack iron mining industry: Mining and Metallurgy, v. 24, no. 443, p. 480–487.

Linney, R. J., 1943, Republic Steel's operations at Port Henry, Mineville, and Fisher Hill: Mining and Metallurgy: v. 24, no. 443, p. 488–502.

Lyell, C., 1845, Travels in North America, v. 1, New York, Wiley and Putman, 231 p.

MacKevett, E. M., Jr., 1963, Geology and ore deposits of the Bokan Mountain uranium-thorium area, southeastern Alaska: U.S. Geological Survey Bulletin 1154, 125 p.

Mackin, J. H., 1952, Reconnaissance geology of the monazite placers of the Long Valley district, Idaho: U.S. Geological Survey Trace Elements Memorandum Report 473, 22 p.

Mackin, J. H., and Schmidt, D. L., 1957, Uranium and thorium-bearing minerals in placer deposits in Idaho: Idaho Bureau of Mines and Geology Mineral Resources Report 7, 9 p.

MacNeil, F. S., 1949, Pleistocene shorelines in Florida and Georgia: U.S. Geological Survey Professional Paper 221-F, p. 95–106.

Martens, J. H. C., 1928, Beach deposits of ilmenite, zircon, and rutile in Florida: Florida Geological Survey 19th Annual Report, p. 124–154.

McKeown, F. A., and Klemic, Harry, 1956, Rare-earth-bearing apatite at Mineville, Essex County, New York: U.S. Geological Survey Bulletin 1046-B, p. 9–23.

Mertie, J. B., Jr., 1953, Monazite deposits of the southeastern Atlantic States: U.S. Geological Survey Circular 237, 31 p.

Milton, Charles, and Blade, L. V., 1958, Preliminary note on kimziyite, a new zirconium garnet: Science, v. 127, no. 3310, p. 1343.

Neiheisel, James, 1962, Heavy-mineral investigation of Recent and Pleistocene sands of lower coastal plain of Georgia: Geological Society of America Bulletin, v. 73, p. 365–374.

Nesbitt, B. E., and Kelly, W. C., 1977, Magmatic and hydrothermal inclusions in carbonatite at the Magnet Cove Complex, Arkansas: Contributions to Mineralogy and Petrology, v. 63, p. 271–294.

Newland, D. H., 1908, Geology of the Adirondack magnetic iron ores: New York State Museum Bulletin 119, no. 423, 182 p.

Olson, J. C., 1974, Geological map of the Rudolph Hill quadrangle, Gunnison, Hinsdale, and Saguache Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1177.

Olson, J. C., Marvin, R. F., Parker, R. L., and Mehnert, H. H., 1977, Age and tectonic setting of lower Paleozoic alkalic and mafic rocks, carbonatites, and thorium veins in south-central Colorado: U.S. Geological Survey Journal of Research, v. 5, p. 673–687.

Olson, J. C., Shawe, P. R., Pray, L. C., and Sharp, W. N., 1954, Rare-earth deposits of the Mountain Pass district, San Bernardino County, California: U.S. Geological Survey Professional Paper 261, 75 p.

Osmond, J. K., Mary, J. P., and Tanner, W. J., 1970, Age of Cape Kennedy barrier and lagoon complex: Journal of Geophysical Research, v. 75, p. 469–479.

Overstreet, W. C., 1967, The geologic occurrence of monazite: U.S. Geological Survey Professional Paper 530, 327 p.

Parker, G. G., and Cooke, C. W., 1944, Late Cenozoic geology of southern Florida: Florida Geological Survey Bulletin 27, 119 p.

Parker, R. L., and Sharp, W. N., 1970, Mafic-ultramafic rocks and associated carbonatites of the Gem Park Complex, Custer and Fremont Counties, Colorado: U.S. Geological Survey Professional Paper 649, 24 p.

Pecora, W. T., 1962, Carbonatite problem in the Bearpaw Mountains, Montana, *in* Engel, A. E. J., James, H. L., and Leonard, B. F., eds., Petrologic studies, A. F. Buddington volume: Geological Society of America, p. 83–104.

Pecora, W. T., and Kerr, J. H., 1953, Burbankite and calkinsite, two new carbonate minerals from Montana: American Mineralogist, v. 38, p. 1169–1183.

Pirkle, E. C., Pirkle, W. A., and Yoho, W. H., 1974, The Green Cove Springs and Boulougne heavy-mineral sand deposits of Florida: Economic Geology, v. 69, p. 1129–1137.

Pirkle, E. C., and Yoho, W. H., 1970, The heavy mineral ore body of Trail Ridge, Florida: Economic Geology, v. 65, p. 17–30.

Reed, J. C., 1937, Geology and ore deposits of the Warren mining district, Idaho County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 45, 65 p.

Reid, R. R., 1960, Placer deposits of the Elk City region: Idaho Bureau of Mines and Geology Pamphlet 121, 26 p.

Robertson, A. F., and Storch, R. H., 1955a, Camp Creek radioactive mineral placer area, Blaine and Camas Counties, Idaho: U.S. Atomic Energy Commission RME-3136, 27 p.

______1955b, Rock Creek radioactive mineral placer area, Blaine County, Idaho: U.S. Atomic Energy Commission RME-3139, 25 p.

Roden, M. K., and Cullers, R. L., 1976, Rare earth element distributions and strontium isotope data from the Gem Park igneous complex, Colorado: Geological Society of America Abstracts with Programs, v. 8, no. 5, p. 622–623.

Santmyers, R. M., 1930, Monazite, thorium, and cerium: U.S. Bureau of Mines Information Circular 6321, 43 p.

Savage, C. N., 1961, Economic geology of central Idaho blacksand placers: Idaho Bureau of Mines and Geology Bulletin 17, 160 p.

Schmidt, R. G., Pecora, W. T., and Hearn, B. C., Jr., 1964, Geology of the Cleveland quadrangle, Bearpaw Mountains, Blaine County, Montana: U.S. Geological Survey Bulletin 1141-P, 26 p.

Shattuck, G. B., 1906, The Pliocene and Pleistocene deposits of Maryland: Maryland Geological Survey Bulletin 4, p. 21–137.

Shawe, D. R., and Parker, R. L., 1967, Mafic-ultramafic layered intrusion at Iron Mountain, Fremont County, Colorado: U.S. Geological Survey Bulletin 1251-A, 28 p.

Staatz, M. H., 1978, I and L uranium and thorium vein system, Bokan Mountain, southeastern Alaska: Economic Geology, v. 73, no. 4, p. 512–523.

Staatz, M. H., Armbrustmacher, T. J., Olson, J. C., Brownfield, I. K., Brock, M. R., Lemons, J. F., Jr., Coppa, L. V., and Clingan, B. V., 1979, Principal thorium resources in the United States: U.S. Geological Survey Circular 805, 42 p.

Staatz, M. H., and Conklin, N. M., 1967, Rare-earth thorium carbonate veins of the Road Gulch area, northern Wet Mountains, Colorado, *in* Geological Survey Research 1966: U.S. Geological Survey Professional Paper 550-B, p. B130–B134.

Staley, W. W., 1952, Monazite in Idaho: The Compass, v. 29, no. 4, p. 303–312.

Stamper, J. W., 1966, Titanium: U.S. Bureau of Mines Minerals Yearbook 1965, p. 939–954.

Stephens, F. H., 1971, The Kendrick Bay project: Western Mines, v. 44, no. 10, p. 151–158.

Stephensen, L. W., 1912, The coastal plain of North Carolina—The Cretaceous, Lafayette, and Quaternary formations: North Carolina Geological Survey Bulletin 3, p. 73–171.

Storch, R. H., 1958a, Ilmenite and other black sand minerals in the Gold Fork placer deposit, Valley County, Idaho: U.S. Bureau of Mines Report of Investigations 5395, 15 p.

______1958b, Ilmenite and other black sand minerals in the Deadwood placer deposit, Valley County, Idaho: U.S. Bureau of Mines Report of Investigations 5396, 15 p.

Storch, R. H., and Holt, D. C., 1963, Titanium placer deposits of Idaho: U.S. Bureau of Mines Report of Investigations 6319, 69 p.

Storch, R. H., and Robertson, A. F., 1954, Beaver Creek monazite placer area, Valley County, Idaho: U.S. Atomic Energy Commission RME-3132, 15 p.

Storch, R. H., Robertson, A. F., and Holt, D. C., 1956, Western and northwestern United States, including Alaska, pt. 1 of Eilertsen, D. E., and Lamb, F. D., A comprehensive report of exploration by the Bureau of Mines for thorium and radioactive black mineral deposits: U.S. Atomic Energy Commission RME-3140, p. 8–28.

Taylor, R. B., Scott, G. R., Wobus, R. A., and Epis, R. C., 1975a, Reconnaissance geologic map of the Cotopaxi 15-minute quadrangle, Fremont and Custer Counties, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-900.

______1975b, Reconnaissance geologic map of the Royal Gorge 15-minute quadrangle, Fremont and Custer Counties, Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-869.

Veatch, J. O., and Stephensen, L. W., 1911, Preliminary report on the geology of the coastal plain of Georgia: Georgia Geological Survey Bulletin 26, 466 p.

Vernon, R. O., 1951, Geology of Citrus and Levy Counties, Florida: Florida Geological Survey Bulletin 33, 256 p.

Winkler, C. D., and Howard, J. D., 1976, Correlation of tectonically deformed shorelines on the southern Atlantic coastal plain: Geology, v. 5, no. 2, p. 123–127.

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