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Planimetric Base from National Atlas 1:7,500,000, 1970.

Scale 1:5,000,000

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PRELIMINARY MAP OF RARE-EARTH PROVINCES IN THE CONTERMINOUS UNITED STATES

BY

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

Introduction

This map, which is part of the atlas of metal and nonmetal provinces in the United States (Tooker, 1979) shows the distribution of known deposits of rare-earth metals. The rare-earth metals comprise the 15 lanthanide—elements having atomic numbers 57 to 71, including lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). One of these, promethium, is not known to occur in nature. Yttrium (Y), with atomic number 39, is also classed with the rare earths because of its chemical similarities and geochemical affinities. The first seven elements listed above (La through Eu) are included in the cerium group of rare earths, so called because cerium is their most common member. The remaining eight elements (Gd through Lu, together with Y) are called the yttrium group. The proportion of the two groups are sufficiently distinct that in many minerals one group will predominate over the other. The lanthanides readily substitute for one another in various minerals because of similarity of the outermost part of their atomic structures.

Rare-earth minerals comprise over 100 different varieties (Adams and Theobald, 1973, p. 111-151). Production, however, has come from only a few: monazite, bastnasite, and xenotime. Monazite, principally from beach placers, was the main source of domestic rare earths until the mid 1950's. The discovery of the bastnasite-rich massive carbonatite at Mountain Pass, Calif., changed the supply picture and the United States gradually changed from importing most of its rare earths to becoming an exporter. In 1975, 90 percent of the domestic rare earths came from Mountain Pass. Although some foreign-produced monazite was still used by some domestic manufacturers, about 3,400 metric tons (t) of bastnasite was also exported to 25 foreign countries, according to its sole producer, Molybdenum Corporation of America, (Smith, 1976, p. 1215). The principal rare-earth-producer nations, as of 1975 after the United States, are Australia, USSR, India, and Malaysia (U.S. Bur. Mines, 1976, p. 137).

Resources of rare earths are large, both in the United States and elsewhere. Shortage in these elements is not predictable in the foreseeable future, even in a large increase in usage occurs. The rare-earth metals are considerably in quantity, and cerium and lanthanum commonly are the most abundant.

The rare earths have a small but growing market, chiefly in industrial uses. They were first used as a minor additive in the manufacture of iron oxides. Since then new uses have been found, particularly during the 10 years from 1966 to 1975. In this period, domestic use of rare-earth oxides increased from 5,200 t in 1966 to a high of 17,000 t in 1973, and then dropped off to 11,600 t by 1975 (Smith, 1976, p. 1215). Increase of rare-earth domestic usage just between 1966 and 1975 was 77% percent, not counting a sudden spurt in 1973 and 1974, when a large increase in demand for use of rare earths in pipeline steel caused the building of the Alaska pipeline. The increase over this 10 year period has been almost 10 percent a year, due principally to the reduction in usage now even for rare earths. The U.S. Bureau of Mines (1975, p. 137) predicted a growth in the industry of 7 to 8 percent a year for the next five years. A new use for rare earths, however, could increase this figure several fold.

The principal uses in 1975 were as a catalyst for petroleum cracking (45 percent), alloys with iron and steel (35 percent), and ceramics and glass additives (16 percent). For most of these uses a mixture of rare earths was used. In addition, however, small quantities of high purity europium, terbium, and gadolinium compounds were used in electronics, color television tube phosphors, and in lasers (Adams and Theobald, 1973, p. 130).

Explanation map features

Map distinctions are made for a variety of types of rare-earth deposits. Each variety has different potential, both as to present and future production. Some types may be large low-grade sources of rare-earth metals; other types contain only limited amounts of high-grade rare earths. Grade of the deposits is of course an important factor in ore future productivity, but the future of any of these deposits is not dependent entirely upon grade. Some high-grade deposits, because of their small size, as in many gemstone and some veins, are unimportant. Some very low grade deposits, on the other hand, because they are large, and the rare earths produced as a byproduct of some other metals, are producers of rare earths. An example of this type of deposit is the placer sands of northern Florida, which are mined principally for titanium. Heavy mineral sand concentrate from Green Cove Springs (now a deposit that contained only 0.03 percent of rare earths (Staatz and others, 1980, p. 6-7).

To set at symbols will show all the occurrences that are likely to influence the production potential of all deposits, this we have used a dual symbol system to give as much information as possible. The shape of the symbol indicates the type of deposit in which the rare earths occur, and size different types of deposits are shown on the map. They are as follows: (1) unconsolidated alluvial or beach placers, (2) consolidated or fossil placers, (3) pegmatites, (4) carbonatite dikes, (5) massive carbonatites, (6) veins, (7) concentrations in metamorphic rocks, generally biotite schist, (8) large disseminated deposits, and (9) concentrations in iron deposits, mainly in apatite. Trace amounts of rare earths also occur in granitic rocks in some areas and may be important as by-products or as indicators of rare-earth deposits in a particular region. Some have a potential to be considered as an economic deposit in the foreseeable future and are also shown on the map. They are listed in table 1 by those areas containing other rare-earth deposits. In addition, the size of the symbol indicates whether a particular deposit is a large producer, type A; small producer or deposit with great potential, type B; or inactive deposits having a small or minor potential, type C. Only one deposit, the Molybdenum Corporation of America's Mountain Pass deposit, is classified as a type A deposit. Bastnasite is mined here from a massive carbonatite deposit. This mine, which is the world's largest producer of rare earths, produces about 40 percent of the United States needs as well as exports abroad. Type B includes small present and past producers, such as Hallidays Mountain, Ga.; Bear Lodge, Climax, Colo.; Iron Hill, Idaho; and Green Cove Springs, Fla. In two of these deposits, Climax and Green Cove Springs, the rare-earths are but a minor byproduct. Domestic production is entirely dependent on the production of molybdenum at Climax and on titanium and zircon at Green Cove Springs. The large disseminated deposits, Bear Lodge Mountains and Hicks Dome, are also included in type B because of their potential as future producers.

The shapes of the various symbols in map areas also take into account certain physical features and economic considerations as to the type of mining or milling. A particular area, for example, placers are divided into unconsolidated and consolidated (or fossil) placers, because other physical factors of processing them, and unconsolidated placers, like those that occur in the southern coastal plain (Staatz, 1979), are considered favorable to the Gold Hundred district, Georgia, as economic ilmenite beds from the Upper Cretaceous of Georgia, Colorado, Utah, and New Mexico, to name those that are considered unconsolidated alluvial or beach placers. The latter can be mined by a dredge and two chief types: (1) those that contain only monazite, and (2) those that contain monazite, xenotime are divided into carbonatite dikes and massive carbonatites. Carbonatite dikes are those, like some rare-earth-grade and mineralogy as a massive carbonatite, but the difference is made where the latter was commercial or else this the former.

Relation to theories

Rare earths commonly occur with thorium deposits in areas containing alkalic rocks such as monzonite, carbonatite, carbonate dikes, disseminated deposits, or veins. The rare-earth-thorium rocks in these districts can be highly variable, but in general the rare earths are much more plentiful than thorium in the carbonatites, and somewhat less abundant than thorium in the veins. The two also occur together in iron deposits in apatite and in segregations in metamorphic rocks. In both types of deposits the rare earths are much more common than thorium. The disseminated rare-earth deposit is a new type that has been described recently by Staatz and others (1979, p. 26-27). These deposits consist of monazite shell rare-earth-bearing nodules crisscrossing a host rock to form a large low-grade deposit. This type of deposit, and to some placer disseminated deposits, contain large resources of rare earths. One of the most numerous types of rare-earth deposits is pegmatites. They are generally found the largest and best crystallized rare-earth minerals. Rare-earth content of pegmatites, however, is generally small and production has been limited to a few tons of a specific mineral, such as euxenite or cleveite. Rare-earth-bearing pegmatites are probably most important in delineating areas in which rare earths are available to form other types of deposits. The location of the rare-earth bearing pegmatites shown on the map are largely derived from a compilation made by Mann, Arengi, and Parrish (1980).

Description and evaluation of rare-earth provinces

Previous boundaries are put around areas where known primary rare-earth deposits are most abundant. They indicate areas in which rare-earth deposits are fairly common and presumably the crust contains above-average amounts of rare earths. Deposits may be all of one type, but the area is more favorable when a variety of deposits of different ages occur. The boundaries of these areas are drawn on the basis of available data and can be extended if other new deposits are found.

The various types of deposits and occurrences and their potential to future domestic sources of rare earths are discussed in table 1 and located on the map. The two areas containing the highest potential for rare-earth deposits are the Mohave Desert (no. 7) on Mesa and the southern part of the Cordilleran belt. Another area, which seems to have considerable potential but is difficult to evaluate, is the Great Plains and the broad areas of Cretaceous sedimentary rocks. Rare-earth deposits have been found here in a few places where these rocks have been breached by erosion. Some such as at Lemhi Pass (no. 15), Bearpaw Mountains (no. 4), Heritage Mountains (no. 13), Elk Creek (no. 15), or at Hicks Dome (no. 16).

Most of the localities shown in the Cordilleran belt are in old continental crustal rocks, and a large part are either Precambrian in age or have been intruded into Precambrian rocks. Only a few deposits occur along either the Pacific or Atlantic coasts in the oceanic or islandarc crustal rocks that were added to the old continental in the Mesozoic. These areas appear to be unfavorable for the discovery of large rare-earth deposits.

Certain types of deposits appear more favorable and hence greater future potential for rare earths than others. The most favorable provinces are those in which deposits are related to alkalic rocks—massive carbonatites, disseminated deposits, veins, and carbonatite dikes. Bastnasite and xenotime that contain these types of deposits are the most rare earth ores (no. 2), Bearpaw Mountains (no. 4), Bokan Mountain (no. 7), Powderhorn-Wet Mountain (no. 10), Gallinas and Capitan Mountains (no. 12), Bear Lodge Mountains (no. 13), Coastal Peak (no. 15), Elk Creek (no. 15), and Hicks Dome (no. 16). Not all of these areas contain large deposits, but they contain the one deposit probably deposit (type A) and over 90 percent of the domestic resources. resources tabulated from two recent resource studies (Staatz and others, 1979, 1980). These types of deposits occur in four rare-earth provinces in the Cordilleran belt east of the boundary separating continental crust from accreted oceanic crust. They occur in five widely scattered localities within the Great Plains and in the basins area on the Precambrian Shield. None are known from the Appalachian belt or Coast Plain.

Certain types of deposits are less favorable as future producers because of their general small size. These include pegmatites and local concentrations in metamorphic rocks. Thus, provinces 8, 9, and 11, where the deposits are principally of these types, are not as favorable as those in which skarn rocks are present. Skarn alone, however, will not determine which deposits will become producers. Some of the unconsolidated placers, because of their type of handling, low cost of operations, and presence of byproducts, will probably be considered before some larger and higher grade deposits. Rare earths in apatite in iron ocean can also be easily separated. Iron tailing piles in the Mesabi, N. Y., area contain approximately 720,000 t of apatite (Staatz and others, 1980), p. 26) that contains approximately 15.1 percent total rare earths (Dickson and Kleatz, 1978, p. 7).

Master deposits may be of little aid in outlining province boundaries. In some places, as at the Idaho batholith (no. 1) and the Piedmont province (no. 19), they are but little removed from the granitic and as-synergic rocks from which they are derived. In these two areas the higher grade placers help in outlining these provinces. In other areas they are far removed from their original source. One of the monazite derived from the Piedmont was carried from Virginia to be deposited in the sea during Tertiary time where it was incorporated in the Waccamaw Formation of late Tertiary age and other later formed, Tertiary units. The rocks have since been eroded and a second generation of placers formed. These placers are shown on the map southeast of province number 19, along the west edge of the Coastal Plain. Some of the monazite originally derived from the Piedmont was carried at later time to the ocean, where it was transported southward by offshore currents to southern Georgia and northern Florida. Here additional placers were formed in Pleistocene and Holocene times. The monazite in these deposits are far removed from the site of their original formation, and the presence of monazite in these placers does not make the surrounding area favorable for rare earths. Examples of these deposits are shown in the Upper Pleistocene sediments of coastal terrace (no. 5) and the Colorado Plateau (no. 8). The monazite in these placers also is apparently derived from granitic and related rocks, and these two areas are not considered primary rare-earth provinces.

Another important factor in the evaluation of rare-earth deposits is whether they are mined as an only or as a byproduct of other rare earths. Most of the consumption as well as much of the production is of cerium-group rare earths, but for certain uses the yttrium group of rare earths are in demand. Deposits that contain substantial amounts of yttrium-group rare earths are more common. Deposits of this type in the conterminous United States include: the apatite in the iron deposit in the Iron Hill area, at Laughlin Peak, N. Mex., and the disseminated deposit at Hicks Dome, Ill.

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Table 1.—Location, types of deposits, estimates of resource potential, and the state of resource information of rare-earth-bearing areas in the conterminous United States

Number	Area location: State(s)	Area	Geologic types of deposits[1]	Preliminary estimates of resource potential: High	Medium	Low	Unknown	State of geologic resource information: Adequate	Insufficient
1.	Idaho	Idaho batholith	I, X	—	X	—	—	—	X
2.	Idaho and Montana	Lemhi Pass area	IV, V, IX, X	—	X	—	—	—	X
3.	Montana	Northwest edge of Great Plains	IX	—	—	X	—	—	X
4.	Montana	Bearpaw Mountains	IX, X	—	—	X	—	—	X
5.	Wyoming	Central Wyoming	II, IX	—	—	X	—	—	X
6.	California	Southern California batholith	VII, IX	—	—	X	—	—	X
7.	California, Arizona, and Nevada	Mohave Desert	II, VII, IV, V, VII, IX, X	X	—	—	—	—	X
8.	Colorado, Utah, Arizona, and New Mexico	Colorado Plateau	II	—	—	X	—	—	X
9.	Colorado and Wyoming	Front Range	II, VI, VII, IV, X	—	—	X	—	—	X
10.	Colorado	Powderhorn-Wet Mountains	III, IV, V, IX	X	—	—	—	—	X
11.	New Mexico	Petaca-Garding	IX	—	—	X	—	—	X
12.	New Mexico	Gallinas and Capitan Mountains	V	X	—	—	—	—	X
13.	Wyoming	Bear Lodge Mountains	IV, V, VI	X	—	—	—	—	X
14.	New Mexico	Laughlin Peak	V	—	—	X	—	—	X
15.	Montana	Elk Creek	III	—	—	X	—	—	X
16.	Illinois	Hicks Dome	VI	X	—	—	—	—	X
17.	New York	Adirondack Mountains	VIII, IX	—	X	—	—	—	X
18.	New York and New Jersey	Reading Prong	II, X, VII, VIII, IX	—	X	—	—	—	X
19.	Virginia, North Carolina, South Carolina, Tennessee, and Georgia	Piedmont Province	I, VII, IX, X	—	X	—	—	—	X
20.	Florida and Georgia	Northeast Florida and southeast Georgia	I	—	—	X	—	—	X

[1]Index to geologic types of deposits and occurrences:
I. Unconsolidated alluvial or beach placers
II. Consolidated or fossil placers
III. Massive carbonatite
IV. Carbonatite dikes
V. Veins
VI. Disseminated deposits
VII. Local concentrations in metamorphic rocks
VIII. Concentrations in iron deposits, mainly in apatite
IX. Local concentrations in pegmatites
X. Trace amounts in granitic rocks