U.S. GEOLOGICAL SURVEY CIRCULAR 930-L

International Strategic Minerals Inventory Summary Report—Zirconium

Prepared as a cooperative effort among earth-science and mineral-resource agencies of Australia, Canada, the Federal Republic of Germany, the Republic of South Africa, the United Kingdom, and the United States of America

Geologic Time Scale

Age			Million years before present
Holocene	Quaternary	CENOZOIC	0.01
Pleistocene	Quaternary	CENOZOIC	2
Pliocene	Tertiary	CENOZOIC	5
Miocene	Tertiary	CENOZOIC	24
Oligocene	Tertiary	CENOZOIC	38
Eocene	Tertiary	CENOZOIC	55
Paleocene	Tertiary	CENOZOIC	63
Late Cretaceous	Cretaceous	MESOZOIC	96
Early Cretaceous	Cretaceous	MESOZOIC	138
Jurassic		MESOZOIC	205
Triassic		MESOZOIC	~240
Permian		PALEOZOIC	290
Pennsylvanian	Carboniferous	PALEOZOIC	~330
Mississippian	Carboniferous	PALEOZOIC	360
Devonian		PALEOZOIC	410
Silurian		PALEOZOIC	435
Ordovician		PALEOZOIC	500
Cambrian		PALEOZOIC	~570
PRECAMBRIAN	Late Proterozoic	PROTEROZOIC	900
PRECAMBRIAN	Middle Proterozoic	PROTEROZOIC	1600
PRECAMBRIAN	Early Proterozoic	PROTEROZOIC	2500
PRECAMBRIAN		ARCHEAN	

International Strategic Minerals Inventory Summary Report—Zirconium

By Roy R. Towner

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FOREWORD

Earth-science and mineral-resource agencies from several countries started the International Strategic Minerals Inventory in order to cooperatively gather information about major sources of strategic mineral raw materials. This circular summarizes inventory information about major deposits of zirconium, one of the mineral commodities selected for the inventory.

The report was prepared by Roy R. Towner of the Australian Department of Primary Industries and Energy. It was edited by David M. Sutphin and transcribed by Dorothy J. Manley of the U.S. Geological Survey (USGS). Zirconium inventory information was compiled or supplied by Roy R. Towner (chief compiler); Dennis B. Fortowski, Australian Bureau of Mineral Resources, Geology and Geophysics; Tyson C. Birkett and Daniel G. Richardson, Canadian Department of Energy, Mines & Resources (EMR), Geological Survey of Canada; Alfred G. Johnston, EMR, Mineral Policy Sector (MPS) (retired); Sebastiaan J. Van Graan, South African Department of Mineral and Energy Affairs, Minerals Bureau; Richard J. Fantel, U.S. Bureau of Mines (USBM); and Eric R. Force and Curtis E. Larsen, USGS. Additional contributions to the report were made by Antony B.T. Werner, EMR, MPS; John H. DeYoung, Jr., USGS; and Aldo F. Barsotti, USBM.

Director

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INTERNATIONAL STRATEGIC MINERALS INVENTORY SUMMARY REPORT

Zirconium

By Roy R. Towner[1]

Abstract

Zircon, a zirconium silicate, is currently the most important commercial zirconium-bearing mineral. Baddeleyite, a natural form of zirconia, is less important but has some specific end uses. Both zircon and baddeleyite occur in hard-rock and placer deposits, but at present all zircon production is from placer deposits. Most baddeleyite production is from hard-rock deposits, principally as a byproduct of copper and phosphate-rock mining.

World zirconium resources in identified, economically exploitable deposits are about 46 times current production rates. Of these resources, some 71 percent are in South Africa, Australia, and the United States. The principal end uses of zirconium minerals are in ceramic applications and as refractories, abrasives, and mold linings in foundries. A minor amount, mainly of zircon, is used for the production of hafnium-free zirconium metal, which is used principally for sheathing fuel elements in nuclear reactors and in the chemical-processing industry, aerospace engineering, and electronics.

Australia and South Africa are the largest zircon producers and account for more than 70 percent of world output; the United States and the Soviet Union account for another 20 percent. South Africa accounts for almost all the world's production of baddeleyite, which is about 2 percent of world production of contained zirconia. Australia and South Africa are the largest exporters of zircon. Unless major new deposits are developed in countries that have not traditionally produced zircon, the pattern of world production is unlikely to change by 2020. The proportions, however, of production that come from existing producing countries may change somewhat.

Manuscript approved for publication October 17, 1991.

[1] Author was formerly with the Bureau of Mineral Resources, Geology and Geophysics and is now with the Bureau of Agricultural and Resource Economics, both in the Australian Department of Primary Industries and Energy.

PART I—OVERVIEW

INTRODUCTION

The reliability of future supplies of so-called strategic minerals is of concern to many nations. This widespread concern led to duplication of effort in the gathering of information on the world's major sources of strategic mineral materials. With the aim of pooling such information, a cooperative program named International Strategic Minerals Inventory (ISMI) was started in 1981 by officials of the governments of the United States, Canada, and the Federal Republic of Germany. They were subsequently joined by the Republic of South Africa, Australia, and the United Kingdom.

The objective of ISMI reports is to make publicly available, in convenient form, nonproprietary data and characteristics of major deposits of strategic mineral commodities for policy considerations in regard to short-term, medium-term, and long-term world supply. This report provides a summary statement of the data compiled and an overview of the supply aspects of zirconium in a format designed to benefit policy analysts and geologists. Knowledge of the geologic aspects of mineral resources is essential in order to discover and develop mineral deposits. However, technical, financial, and political decisions must also be made, and often transportation and marketing systems must be constructed before ore can be mined and processed and the products transported to the consumer; the technical, financial, and political aspects of mineral-resource developments are not specifically addressed in this report. This report addresses only primary stages in the supply process for zirconium and does not include considerations of zirconium demand.

The term "strategic minerals" is imprecise. It generally refers to mineral ore and derivative products that come largely or entirely from foreign sources, that are difficult to replace, and that are important to a nation's economy, in particular its defense industry. In general, the term relates to a nation's perception of vulnerability to supply disruptions and its concern to safeguard its industries from the disruptions of a possible loss of supplies.

Because a mineral that is strategic to one country may not necessarily be strategic to another, no definitive list of strategic minerals can be prepared. The ISMI Working Group decided to commence with chromium, manganese, nickel, and phosphate. All of these studies, plus those for platinum-group metals, cobalt, titanium, graphite, lithium, tin, and vanadium, have now been published. Additional studies on zirconium (this report), tungsten, rare earths and yttrium, and niobium (columbium) and tantalum have been subsequently undertaken.

The data in the ISMI zirconium inventory were collected from July 1987 to October 1988. The report was submitted for review and publication in December 1989. The information used was the best available to the various agencies of the participating countries that contributed to the preparation of this report. Those agencies were the Bureau of Mineral Resources, Geology and Geophysics of the Australian Department of Primary Industries and Energy; the Bureau of Mines and the Geological Survey of the U.S. Department of the Interior; the Geological Survey of Canada and the Mineral Policy Sector of the Canadian Department of Energy, Mines & Resources; the Federal Institute for Geosciences and Natural Resources of the Federal Republic of Germany; the Geological Survey and the Minerals Bureau of the Department of Mineral and Energy Affairs of South Africa; and the British Geological Survey, a component of the Natural Environment Research Council of the United Kingdom.

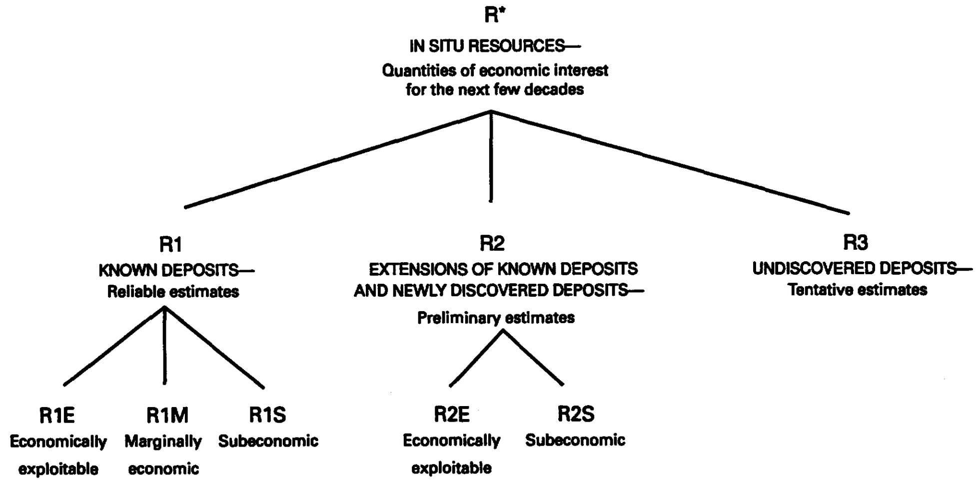
No geologic definition of a deposit or district is used for compiling records for this report. Deposits and districts are selected for the inventory on the basis of their present or expected future contribution to world supply. Records for all deposits compiled by ISMI participants meet this general "major deposit" criterion and are included in the inventory. No information is provided on deposits that were once significant but whose resources are now considered to have been depleted. Some records, for example those from the Guangdong Province in China, refer to districts that contain several deposits; these deposits are grouped together because they are too small to be listed individually or because published data are available only for the deposits as a group.

The ISMI record collection and this report on zirconium have adopted the international classification system for mineral resources recommended by the United Nations Group of Experts on Definitions and Terminology for Mineral Resources (United Nations Economic and Social Council, 1979; Schanz, 1980). The terms, definitions, and resource categories of this system were established in 1979 to facilitate international exchange of mineral-resource data; the Group of Experts sought a system that would be compatible with the several systems already in use in several countries. Figure 1 shows the United Nations (U.N.) resource classification used here. This report focuses on category R1, which includes reliable estimates of tonnages and grades of known deposits. The familiar term "reserves," which many would consider to be equivalent to r1E or R1E, has been interpreted inconsistently and thus has been deliberately avoided in the U.N. classification.

It should be noted that, generally, until a deposit has been extensively explored or mined, its size and grade are imperfectly defined. In many cases, deposit size will prove to be significantly larger, sometimes even several times larger, than was established when the decision to mine was made. Experts with a sound knowledge of a deposit and its geologic setting might infer that the deposit extends beyond the bounds reliably established up to that time. Tonnage estimates for such inferred extensions fall into category R2. For major deposits, ISMI records show R2 estimates in the few cases for which they are readily available. Category R3, postulated but undiscovered resources, is not dealt with in this report.

Not all companies or countries report resource data in the same way. In this report, all resource data are quoted as being in place, and the term "ore" in tables 12 and 13 (Part II) refers to mineralized rock or sediment that contains an economic quantity of zirconium-bearing minerals. Mining recovery from an orebody depends on individual conditions and may vary considerably. For placer deposits, in excess of 80 percent of the ore in place is generally recovered; for open-cut primary deposits, mining recovery is about 75 to 90 percent. After mining, up to about 5 percent of the economic mineral content of alluvial ore may be lost in processing (concentration and separation stages). The recovery rates for hard-rock ore depend on grain size.

The World Bank economic classification of countries (World Bank, 1986, p. 180–181), which is based



*The capital "R" denotes resources *in situ*; a lower case "r" expresses the corresponding *recoverable* resources for each category and subcategory. Thus, r1E is the recoverable equivalent of R1E. This report deals only with R1 and R2, not with R3.

FIGURE 1. United Nations resource categories used in this report (modified from Schanz, 1980, p. 313).

primarily on gross national product (GNP) per capita, is used in this and other ISMI reports to illustrate distribution of resources and production according to economic groupings of countries. This classification was chosen because it relies primarily on objective economic criteria and does not contain political bloc labels that might be perceived differently by different countries.

BACKGROUND, PROCESSING, AND USE

The element zirconium is widely distributed in the Earth's crust and is ranked twentieth among the elements in the list of crustal abundance, higher than copper, tin, lead, and zinc. Nevertheless, zirconium concentration is restricted to just 20 or so minerals. Table 1 lists the more important zirconium-bearing minerals; only zircon, a silicate; baddeleyite, an oxide; and caldasite, a mixture of zirconium-bearing minerals, are of current commercial significance.

Zirconium was first discovered in 1789 by Klaproth and first isolated as a metal (in a crude form) by Berzelius in 1824. Some 90 years later, two Dutch scientists (van Arkel and de Boer) produced high-purity zirconium. Zircon, the name derived from the Persian "zar" meaning gold and "gun" meaning color, has been known since Biblical times as a gem mineral. It was not until 1895 that it was first reported in beach sands. Zircon was first produced during World War I but did not become an important commercial product until about 25 years later.

TABLE 1.—*Zirconium-bearing minerals*

[N.a. = not applicable. —, no data]

Mineral	Chemical formula	Specific gravity	Hardness (Mohs' scale)	ZrO_2 content (percent)
Zircon.......	$ZrSiO_4$	4.2–4.86	7.5	63–67
Baddeleyite..	ZrO_2	5.5–6.0	6.5	98–100
Eudialyte....	$(Na,Ca,Fe)_6Zr(OH,Cl)(SiO_3)_6$	2.9–3.0	5–5.5	1.2
Caldasite[1] ...	N.a.	—	—	60–75
Vlasovite....	$Na_2ZrSi_4O_{11}$	2.97	6	29
Gittinsite	$CaZrSi_2O_7$	3.6	3.5–4.0(?)	40.3
Zirkelite.....	$(Ca,Fe)(Zr,Ti,Th)_2O_5$	4.7	5.5	—

[1] Zirconium material from Brazil consisting of a mixture of fibrous baddeleyite, zircon, altered zircon, and other minerals (Heinrich, 1958, p. 125).

Zircon, which theoretically consists of 67.2 percent zirconia and 32.8 percent silica, also contains between 0.4 percent and 2.0 percent hafnium. In all natural occurrences, zirconium and hafnium always occur together. The similarities of their chemical properties make separation unnecessary for most applications. Inclusions of other minerals such as rutile, magnetite, iron, xenotime, and tin may also be present. In certain zircons, small amounts of radioactive elements such as uranium and thorium sometimes substitute for the zirconium ion in the zircon lattice, or zenotime (YPO_4 with Th and U substituting for Y in small amounts) may be present.

Zircon is a common accessory mineral of igneous rocks, and, because of its resistance to chemical and physical change, it is also a common mineral in sedimentary and metamorphic rocks. However, the mineral is rarely found in commercial quantities in consolidated rocks, and all of the world's zircon is recovered from alluvial deposits, especially beach-sand deposits. The zircon in alluvial deposits is derived from rocks containing zircon that, when subjected to subaerial weathering, break down to liberate their component minerals, such as quartz, feldspar, zircon, and other heavy minerals. These minerals are then transported by rivers to a marine shoreline, where the action of waves, currents, and winds partly removes the lighter minerals such as quartz and thus forms a heavy-mineral deposit containing zircon.

Baddeleyite was first reported as a zirconium mineral in 1892. Originally identified in Brazil and Sri Lanka, baddeleyite may contain up to 1.7 percent hafnium. Brazilian baddeleyite heavily contaminated with radioactive impurities is found in low concentrations in beach deposits. A small amount of baddeleyite is mined in Brazil, but none is mined in Sri Lanka. Baddeleyite is also mined in hard-rock deposits of which the carbonatite complexes of the Kola Peninsula of the Soviet Union and those at Phalaborwa in Northern Transvaal of South Africa are the most important.

Caldasite, a mixture of zirconium minerals including fibrous baddeleyite, zircon, altered zircon, and other minerals (Heinrich, 1958, p. 125), may contain an average of 60 percent zirconia and is produced from deposits in the Poços de Caldas area of Minas Gerais State, Brazil.

Zircon (and baddeleyite when it occurs in placer deposits) is extracted in three distinct stages: mining, wet concentration, and dry separation. Mining of loose and unconsolidated deposits—such as those on Australia's east coast, in Florida, United States, and at Richards Bay, South Africa—is undertaken by dredging methods, whereas some of the older "cemented" deposits—such as those in the Capel and Eneabba areas of Western Australia—are excavated by using dry mining methods based predominantly on self-loading scrapers, bucket-wheel excavators, and bulldozers. Wet concentration involves recovery by using gravity techniques (normally spirals and cones) of a concentrate rich in heavy minerals from the lighter gangue (mainly quartz) that makes up the bulk of the sand. This heavy-mineral concentrate is subsequently divided into its individual components—zircon, ilmenite, rutile, leucoxene, monazite, xenotime, and others—by dry methods based primarily on magnetic, electrostatic, and gravimetric separation techniques. To remove any surface staining on the zircon grains and thereby improve its marketability, zircon may be subsequently upgraded by leaching and calcining.

The recovery of baddeleyite produced as a byproduct of the mining of copper and (or) apatite ores at Phalaborwa, South Africa, requires blasting and the use of front-end loaders, shovels, and other heavy earth-moving equipment. Baddeleyite is recovered from the tailings of the main milling-and-flotation circuit. These tailings are further processed (or reprocessed) in the heavy-mineral plant by gravity separation methods to produce a crude concentrate of baddeleyite and uranium oxides that is then upgraded by chemical methods to high purity materials. Given its relatively low value, the recovery of baddeleyite from an orebody grading 0.18 percent baddeleyite, such as that of the Phalaborwa Complex, is possible only as a part of a large-scale mining operation. In the case of Palabora Mining Company, the total quantity recovered in 1990 was 14,639 metric tons of baddeleyite from about 29 million metric tons of ore treated (Heydari, in press).

Zirconia (ZrO_2) is made by a number of methods, one of which is by decomposing zircon in solution then precipitating zirconium hydroxide, which is roasted to yield zirconia. The decomposition of zircon is achieved either by heating zircon to temperatures in excess of 1,800 °C or by first sintering zircon with alkali or alkaline-earth materials to produce products that are acid soluble (Clough, 1985; Adams, 1985). The process used by ICI Australia Ltd. in Western Australia is believed to be a thermal process, which uses a catalyst or reagent to allow the dissociation of zircon to take place at temperatures less than 1,800 °C and which produces the zirconia in a readily soluble form. Zirconium chemicals and compounds such as sulfates, chlorides, fluorides, and various zirconates are prepared from zirconia.

If magnesium oxide, yttrium oxide, or calcium oxide is added to zirconia, it is possible to stabilize most of the zirconia into a cubic crystal structure that is referred to as partially stabilized zirconia (PSZ). This material has low thermal conductivity, fairly high thermal expansion, and exceptional strength and fracture toughness. A list of the typical properties of PSZ is given in Barnett and Sinha (1986).

Zirconium metal is produced by heating a mixture of zircon sand and coke in the presence of chlorine gas at about 1,200 °C, producing zirconium tetrachloride. This zirconium tetrachloride is dissolved in water to form zirconyl chloride. To produce hafnium-free zirconium, the zirconyl chloride passes through a solvent extraction stage that removes the hafnium. Following solvent extraction, zirconium sulfate is precipitated, filtered, and

TABLE 2.—*Known producers of zirconium metal*

Company	Location	Reported annual capacity (in metric tons)
Teledyne Wah Chang Albany.	Albany, Oregon (U.S.)	3,200
Western Zirconium Inc....	Ogden, Utah (U.S.)	1,400
Cezus	Jarrie, France	2,000
Nippon Mining Co........	Tokyo, Japan	closed in 1982.
Zirconium Industry Co....	Japan	closed in 1984.

calcined, producing zirconium oxide. Zirconium oxide is then mixed with coke and rechlorinated to produce zirconium tetrachloride. The hafnium-free zirconium tetrachloride is reduced in an inert atmosphere with magnesium metal to produce zirconium sponge and magnesium chloride. (This process is known as the Kroll process.) The magnesium chloride is removed, and the zirconium sponge is distilled, crushed, and melted into ingot. About 90 percent of zirconium metal produced is hafnium free and is used for cladding fuel elements in nuclear reactors. Commercial-grade zirconium metal, which has excellent corrosion-resistance qualities, is used as a component in super alloys and in the aerospace engineering, chemical processing, and electronic industries. A list of the world producers of zirconium metal is shown in table 2.

Approximately 95 percent of zirconium consumption is in the form of zircon, zirconia, and other zirconium compounds. Only about 5 percent is for metal and alloy use. Figure 2 illustrates the utilization pattern for zirconium compounds. Zircon is used directly for abrasives and as a welding flux. Zircon sand and flour (milled sand) find application in foundry molds, refractories, ceramics, and refractory paints. Zircon, in the form of sand and flour, is valued in the steel industry for its high fusion point (about 1,750 °C), low thermal expansion, and high thermal conductivity. These

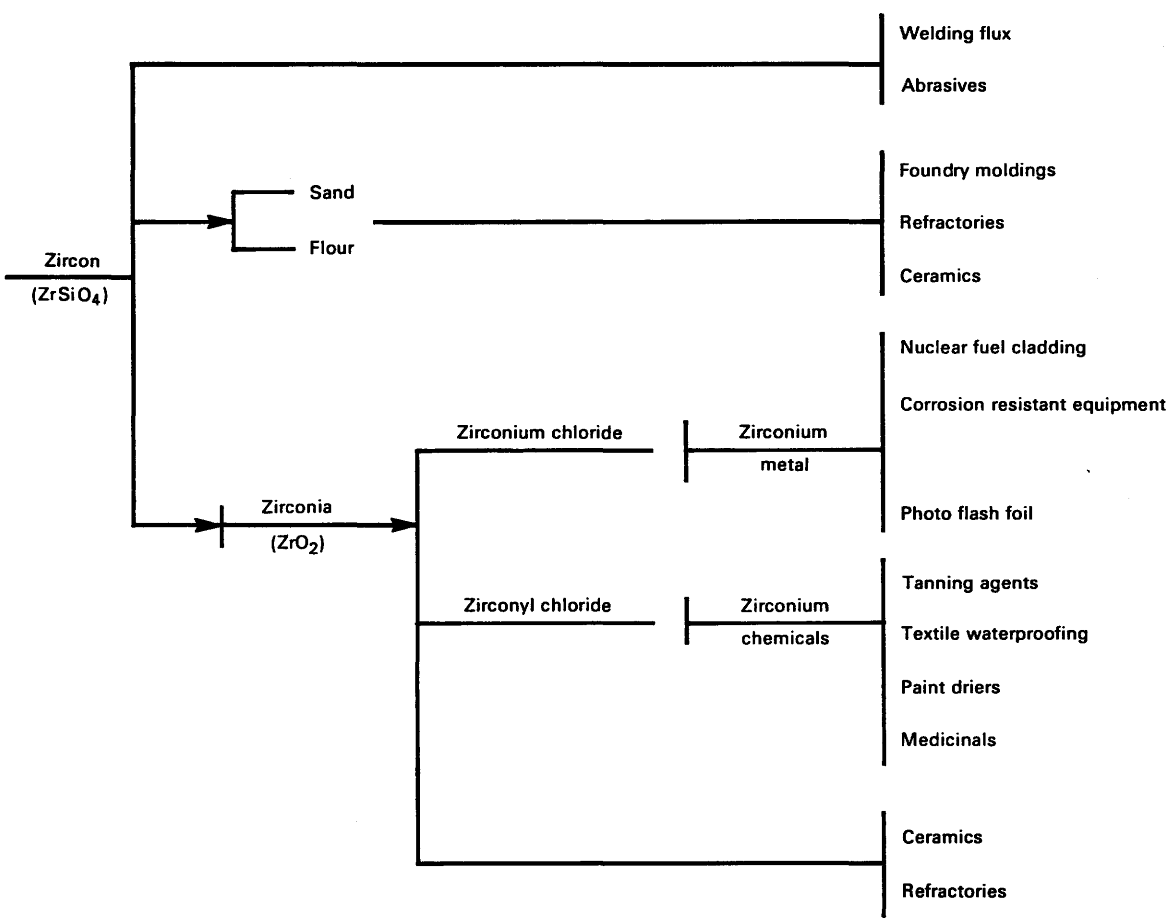


FIGURE 2. Utilization pattern for zirconium compounds.

TABLE 3.—*Estimated consumption of zircon in the United States in 1970, 1980, and 1988, listed by end use*

[Source: U.S. Bureau of Mines, 1970–90. Figures are in metric tons, may not add to totals shown due to rounding, and include an insignificant amount of baddeleyite. Figures in parentheses represent percent of world total. N.r. = not reported. W = withheld to avoid disclosing company proprietary data; included in Total]

End use	Consumption		
	1970	1980	1988
Foundry applications	112,000 (69.0)	50,000 (38.2)	46,600 (35.0)
Zircon refractories[1]	N.r.	26,000 (20.1)	25,000 (18.8)
AZS refractories[2]	24,600 (15.1)	7,000 (5.6)	12,000 (9.0)
Zirconia[3] and AZ abrasives[4]	N.r.	16,000 (12.5)	W
Alloys[5]	25,800 (15.9)	2,000 (1.4)	5,300 (4.0)
Other[6]	N.r.	29,000 (22.2)	W
Total	162,400 (100)	130,000 (100)	133,000 (100)

[1] Dense and pressed zircon bricks and shapes.
[2] Fused, cast, and bonded alumina-zirconia-silica-based refractories.
[3] Excludes oxide produced by zirconium metal producers.
[4] Alumina-zirconia-based abrasives.
[5] Excludes alloys above 90 percent zirconium.
[6] Includes chemicals, metallurgical-grade zirconium tetrachloride, sandblasting, welding rods, and miscellaneous uses.

properties coupled with consistent fineness and even sizing of the natural product make possible high-precision castings having a good surface finish. Traditionally, zircon has been used in the steel industry as facing on foundry molds to increase resistance to metal penetration and to afford a fine, uniform finish.

In the 1950's, about three-quarters of the world's zircon production was used in foundries. Today, this application accounts for only about one-half of the world's production. Japan and the United States are the largest consumers for foundry applications. Table 3 shows consumption of zircon by end use in the United States. The declining importance of the traditional use of zircon in foundries was caused by 1970's price increases that resulted in increased competition from chromite sand, staurolite, and olivine. Zircon-based refractories (both bricks and blocks), because of their inertness and resistance to corrosion and erosion, are used in the glass and aluminum industries, in ladle linings, and in hearths for containing molten metal.

Although baddeleyite is a natural form of zirconia, its use is limited according to purity. The main uses of baddeleyite are as abrasives, refractories, and in ceramic colorants in which the higher cost of manufactured zirconia has limited demand (Dickson, 1985). Table 4 shows a breakdown of the main end uses of baddeleyite worldwide in 1984 and 1987.

Zirconia made from zircon is normally very pure, can be milled to a very fine particle size, and is especially valued in ceramic applications. It is therefore preferred to baddeleyite and commands a higher price. Relatively low-grade manufactured zirconia, however, is used in some of the same applications as baddeleyite, particularly in abrasives and as ceramic colors and depending on the relative price of the two materials. Premium chemically precipitated-grade zirconia and PSZ have low-volume uses but account for about one-third of the value of the zirconia market (Dickson, 1985). Some examples of the use of zirconia and PSZ in high-technology applications include oxygen sensors in car exhaust systems and other industrial applications, the manufacture of lead zirconate titanates for electronic applications such as piezoelectric materials, and polishing compounds (Dickson, 1985).

Other zirconium compounds are used in many low-volume chemical products, including stannous hexafluorozirconate in toothpaste to prevent tooth decay, compounds for use in polymeric waxes, zirconium

TABLE 4.—*Estimated consumption of baddeleyite in the world in 1984 and 1987, listed by end use*

[Sources: Kawata and others, 1986; Rouse, 1988. Figures are in metric tons and may not add to totals shown due to rounding. Figures in parentheses represent percentage of world total]

End use	Consumption	
	1984	1987
Abrasives	3,900 (26)	3,600 (20)
Refractories	8,300 (55)	10,800 (60)
Ceramic colors	1,950 (13)	2,700 (15)
Others[1]	950 (6)	900 (5)
Total	15,100 (100)	18,000 (100)

[1] Zirconium chemicals, raw material for master alloys, welding electrodes, crucibles, setter plates, and zirconia grinding media.

sulfate for leather tanning, and zirconium alkoxides in paints as rust inhibitors and in inks to promote drying.

SUPPLY ASPECTS

As shown in subsequent sections of this report, zirconium resources and production are not uniformly distributed around the world. The geologic factors that control the distribution of zirconium mineral deposits, coupled with the geographical history of economic development, have required that many industrialized nations import zirconium minerals. Several historical aspects of zirconium mineral supply and zircon prices are especially noteworthy:

- During the 1930's, Australia became the world's major producer of zircon sand, and, apart from a brief period during World War II (1939–45), it has maintained this position to the present. In the late 1960's to early 1970's, Australia supplied more than 80 percent of world zircon production and accounted for about 95 percent of world exports of zircon. However, in the mid-1970's, two significant changes took place in the world zircon industry. First, in Australia, the industry focus shifted from the east coast to the west coast, where zircon comprised a lower proportion of the heavy-mineral content of the deposits. Second, large-scale production of zircon began in South Africa. By 1987, Australia's proportion of world production had fallen to about 55 percent, and South Africa accounted for another 20 percent. Australia, however, accounted for some 70 percent of world export trade. The United States and the Soviet Union, the two other major producers of zircon, also sell internationally.
- Since zircon is a byproduct of mineral-sands mining, output levels tend to be influenced by the demand for the titanium minerals rutile and ilmenite. Zircon's byproduct status is reflected in its high degree of price volatility. For example, because of strong demand for titanium minerals in the late 1950's, zircon became oversupplied. Australian producers, therefore, set a floor price in 1962 for standard-grade zircon at A$24 per metric ton free on board (f.o.b.).[2] By 1964, shortages had developed, and prices increased to about A$60 per metric ton. This increase encouraged producers to reprocess accumulated zircon-rich tailings and eventually led to another oversupply situation. In 1971, zircon prices were low, and sales competition between producers was so intense that the Australian Government imposed a minimum export price of A$30 per metric ton f.o.b.
- Until the early 1970's, foundry industries accounted for about 65 percent of world zircon consumption. From 1965 to 1974, however, Japanese consumption of zircon in refractories increased fivefold, from 30,000 to 150,000 metric tons per year. This surge in demand caused shortages in other parts of the world, particularly in Western Europe. The large increase stemmed from the cumulative effect of two simultaneous developments: (1) the technical substitution of pyrophyllite by zircon in monolithic refractory linings in steel ladles and (2) the closure of Japan's main pyrophyllite mines, which accelerated the substitution. Concurrently, zircon production from the east coast of Australia declined from a peak of 357,000 metric tons in 1971 to about 288,000 metric tons in 1974. This decline was due to (1) land-use decisions preventing or inhibiting mining for environmental reasons in a number of locations and (2) a decline in grades. However, this zircon-production decline was offset by increased production from the west coast of Australia from about 52,000 metric tons in 1971 to 73,000 metric tons in 1974.
- The combined effect of increased demand, particularly in Japan, and shortage of supply led to large price increases. Between early 1973 and late 1974, quoted prices increased from less than A$50 per metric ton to A$340 per metric ton for premium-grade zircon and A$290 per metric ton for standard-grade zircon. Spot prices at that time exceeded A$400 per metric ton (Industrial Minerals, 1975). These unprecedented price increases led to some substitution by olivine and chromite, especially by European foundry-sand users. From mid-1974, zircon prices began to fall dramatically in response to the oil-shock-induced worldwide recession. The fall was accentuated by the increased supply from large-scale developments at Eneabba, Australia, and at Richards Bay, South Africa, and was almost as rapid as its rise. Again in November 1975, fierce sales competition among producers, whose stocks were building up at a rate of about 10,000 metric tons per month, prompted the Australian Government to reintroduce a floor-price policy. A two-tier minimum export price system was introduced in 1976—A$140 per metric ton for zircon containing 0.1 percent or more iron oxide and A$150 per metric ton for zircon containing less than 0.1 percent iron oxide. When the floor price was abandoned in early 1977, the price fell, and for the

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[2] Because Australia is a major producer, zircon prices on world markets are quoted in Australian dollars. Consult an appropriate source for exchange rates for the years cited to find the approximate U.S. dollar equivalent of the Australian price. It is important to remember that the equivalent U.S. dollar value derived is not necessarily the price of zircon in the United States at that time.

next 2 years standard-grade zircon was sold at about A$50 per metric ton.

- During the 1981 recession, cutbacks in rutile and ilmenite production caused the supply of zircon to tighten. Prices for standard and premium zircon grades increased in 1983 to A$105–110 per metric ton and A$130–135 per metric ton, respectively. Although rutile and ilmenite production began to increase in the mid-1980's under the influence of strong demand for titanium dioxide from the pigment industry, zircon supplies remained generally tight due to declining zircon grades in the orebodies—particularly in Australia—and mining difficulties in South Africa. This tight supply, together with the increased demand for high-temperature foundry-and-steel-industry refractories, again forced prices up—from A$120 per metric ton for standard-grade zircon in January 1985 to A$600 per metric ton in mid-1988. Spot prices were reported to have reached A$1,000 per metric ton or higher. In 1984, world production of manufactured zirconia and baddeleyite was estimated to be 6,000 to 8,000 metric tons and about 12,000 to 15,000 metric tons, respectively (Dickson, 1985; Kawata and others, 1986). The chief source of baddeleyite is currently Phalaborwa, South Africa, where production increased to 27,000 metric tons per year in 1990 (production was 17,500 metric tons in 1985) (Kawata and others, 1986; Heydari, in press).
- A relatively new product, micronized zircon, has a growing market. This zircon gives a satin finish to tiles and has as its largest single market the Italian tile industry, which consumes an estimated 40,000 metric tons per year.

DISTRIBUTION OF ZIRCONIUM DEPOSITS

The world map in figure 3 shows the locations of 64 major zirconium deposits and districts. Some of the map locations represent several sites within a country or district (but only one inventory record has been prepared). For example, seven mining districts (including two in China's Guangxi Province) are represented by the map symbol for Guangdong Province, China, and three deposits and mines are represented by the symbol for Wuzhaung district, China. The locations of zirconium deposits in the Guangdong and Guangxi Provinces and the Hainan Island are shown in figure 4.

Identified major zirconium deposits occur on every continent except Antarctica, but those in the ISMI zirconium inventory are located only in relatively few (13) countries. Deposits are scarce in central and north Africa, Europe, and South America excluding Brazil. Also noteworthy is that many of the deposits, as in Australia, South Africa, and China, are grouped in provinces. Figure 5 shows the global distribution of major zirconium deposits and districts according to the economic class (GNP per capita) of the countries where they are located.

Zirconium mineral deposits in this report are of two distinctly different geologic types: (1) secondary deposits as placers and (2) primary igneous deposits that are subdivided into those of magmatic or volcanic origin. Figure 3 shows 55 locations of secondary placer deposits and 9 locations of primary igneous deposits and indicates the size of the deposits or districts at each location. Sixteen deposits contain more than 1 million metric tons of zirconium each, and 34 deposits contain less; information on deposit size for the remaining 14 deposits was not reported.

Placer deposits are composed generally of unconsolidated sand that is enriched in heavy minerals, including zirconium minerals. The zirconium minerals, principally zircon, originally occurred as accessory constituents in other rocks and become valuable only after they have been released by weathering and subsequently concentrated by geological processes. Zirconium minerals originate from a variety of primary source rocks ranging from simple quartz veins to complexes of volcanic, magmatic, and (or) metamorphic origin as well as from sedimentary rocks, such as sandstone and conglomerate, which can, in some cases, provide important secondary sources for deposits.

Economic concentrations in placers occur wherever an area of source rocks has yielded sufficient quantities of zirconium minerals and where physiography has provided suitable conditions for deposition. Most placer deposits are marine in origin; the remainder are fluvial. The majority are Quaternary (younger than 2 million years in age) and occur on or very near to the surface. However, buried placer deposits, such as the Tertiary deposits of Eneabba, Australia, and Dnepropetrovsk in the Soviet Union, are also important. All placer deposits contain heavy minerals other than zirconium minerals—principally the titanium minerals, rutile and ilmenite. In fact, zirconium minerals are usually a coproduct or a byproduct of mining for titanium minerals. No placer deposit is currently mined solely for zirconium minerals. Most placer deposits have combined heavy-mineral grades of 10 to 20 percent. Deposits having grades less than 5 percent heavy minerals may be mined economically at 1990 prices provided the rutile and ilmenite content is high. The easily minable character of some placer deposits, such as those in eastern Australia, allows mining of grades of less than 1 percent

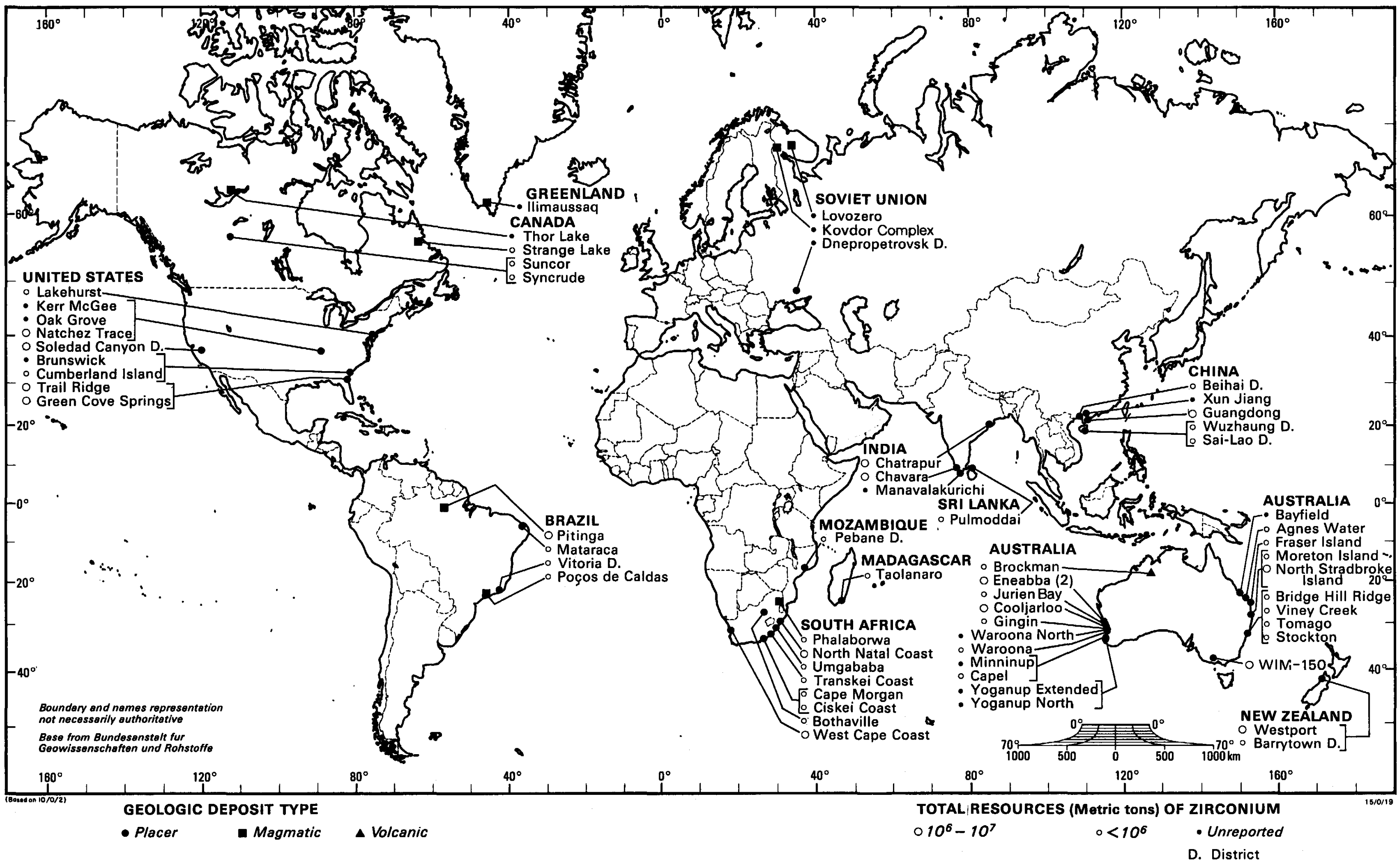


FIGURE 3. Location, geologic deposit type, and total resources of the world's major zirconium mineral deposits and districts. Number in parentheses (following Eneabba, Australia) indicates the number of records (deposits or districts). Location names are from tables 13 and 14 in Part II.

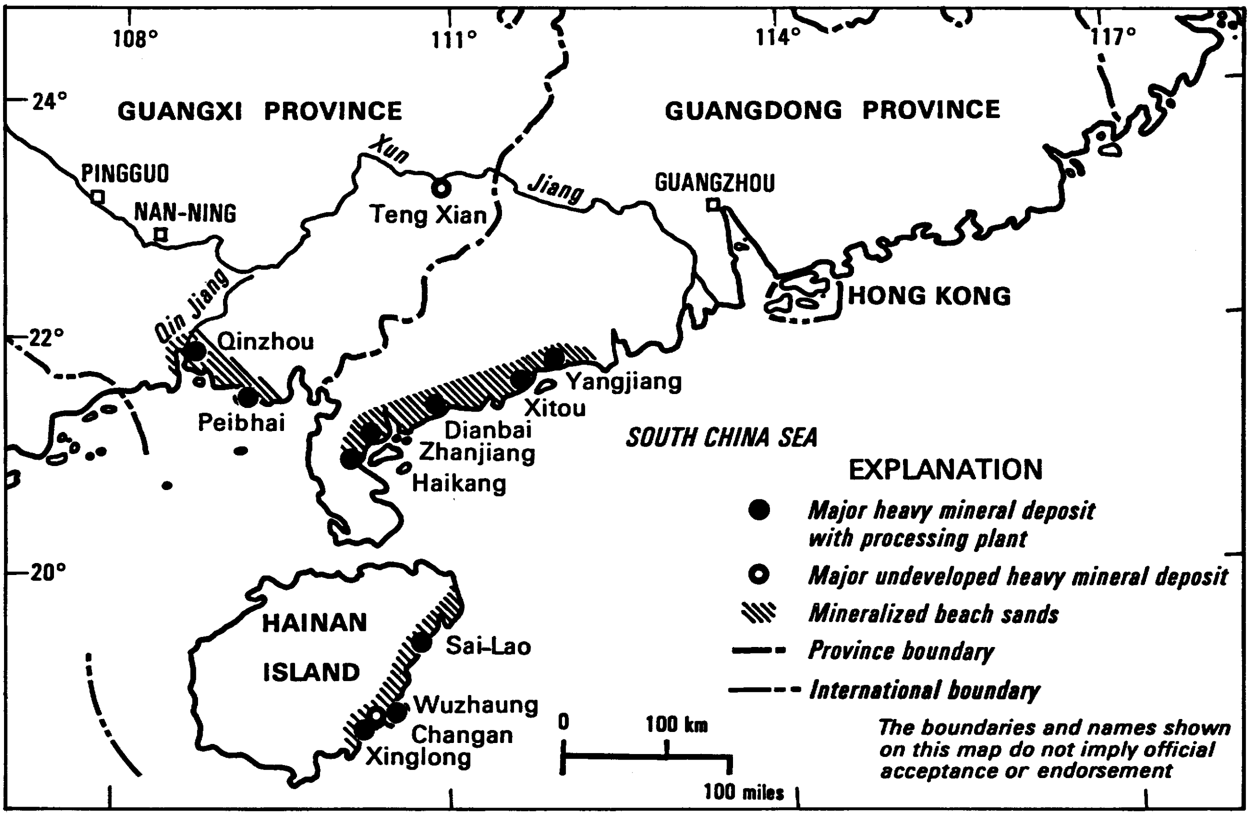


FIGURE 4. Zirconium mineral deposits in Guangdong and Guangxi Provinces and Hainan Island, China.

combined heavy minerals. Figure 6 is a schematic sketch of a secondary dune placer deposit, and figure 7 is a sketch of a buried placer deposit similar to those at Yoganup and Eneabba, Australia.

Alluvial placer deposits also occur at Dnepropetrovsk in the Soviet Union and at Xun Jiang in China. Resource and production data for these deposits are not available to the ISMI inventory. The Dnepropetrovsk district is the principal source of zirconium minerals in the Soviet Union, and the Xun Jiang deposit in China is not currently being mined.

Of the nine nonplacer, primary igneous deposits listed in the ISMI inventory, the host rocks are alkaline to peralkaline granite or granitic rocks (Pitinga, Brazil; Thor Lake, and Strange Lake, Canada; Ilimaussaq, Greenland; and Lovozero, Soviet Union); other deposits are associated with carbonatite alkalic intrusions (Phalaborwa, South Africa; Kovdor Complex, Soviet Union; and Poços de Caldas, Brazil), and one (Brockman, Australia) is associated with altered volcanic tuffs. Most deposits are Precambrian in age. Data on the resources of, and production from, a number of these deposits are not recorded in the inventory. Only three of these magmatic deposits produce zirconium minerals (baddeleyite from Phalaborwa, South Africa, and Kovdor Complex, Soviet Union, and caldasite from Poços de Caldas, Brazil). In some of these hard-rock deposits, the more unusual forms of zirconium minerals, such as gel-zircon, gittinsite, and eudialyte, occur. None of these minerals are commercially minable at present.

Zircon is also associated with alluvial tin deposits in Malaysia and Thailand and the deeply weathered primary tin deposit at Pitinga in Brazil. There are no separate resource data available for the deposits in Malaysia and Thailand for the ISMI inventory, but, although they are large suppliers of alluvial tin, they are considered to be very small suppliers of alluvial zircon. In contrast, in the Pitinga tin deposit, which only recently began recovering zircon, significant resources amount to about 5 percent of the world's R1E resources of that mineral. This deposit is in the upper part of a deeply and intensely weathered granite body. Alluvial mining methods are used, but the deposit is classified as primary in this report. Table 5 shows a list of zirconium prospects, deposits, and districts not included in the ISMI inventory.

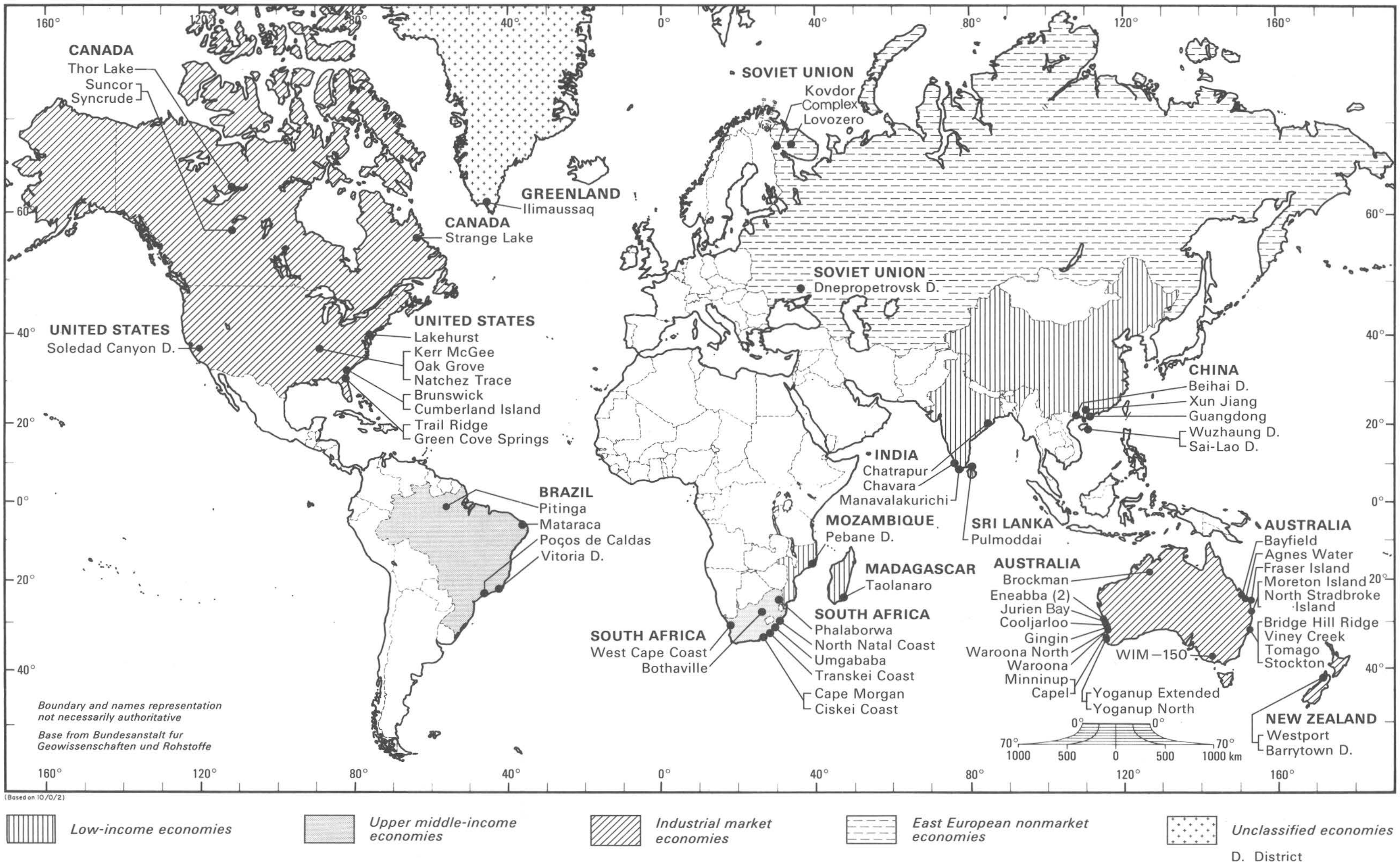


FIGURE 5. Economic classification of the World Bank (1986, p. 180–181) for countries containing major zirconium mineral deposits and districts. Number in parentheses (following Eneabba, Australia) indicates the number of records (mines and deposits). Location names are from tables 13 and 14 in Part II.

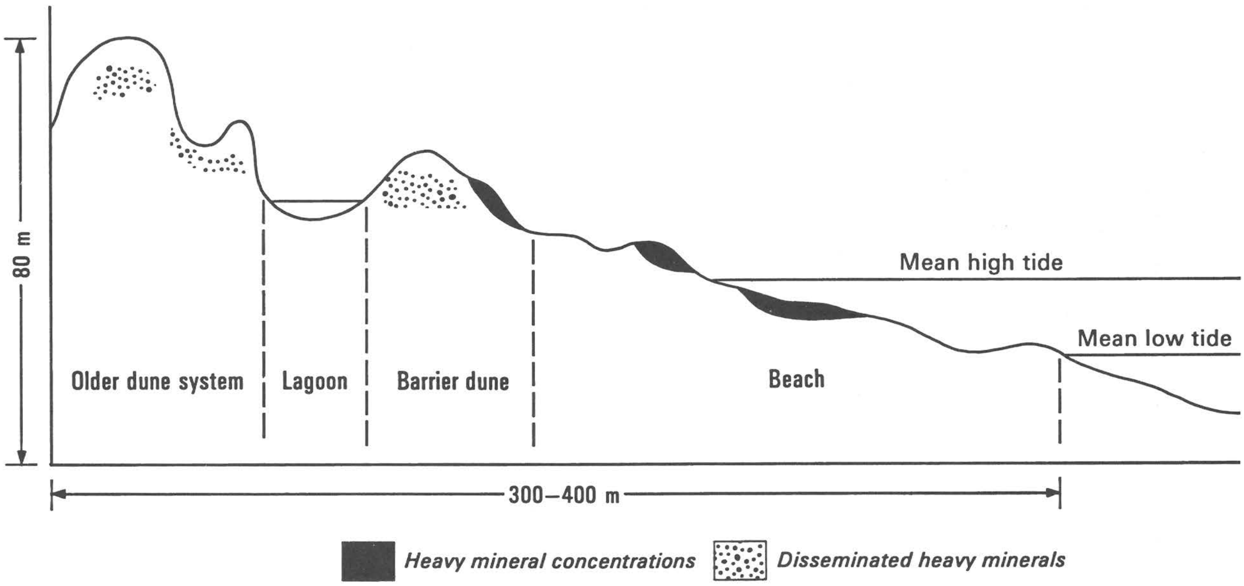


FIGURE 6. Schematic sketch of a secondary dune placer deposit.

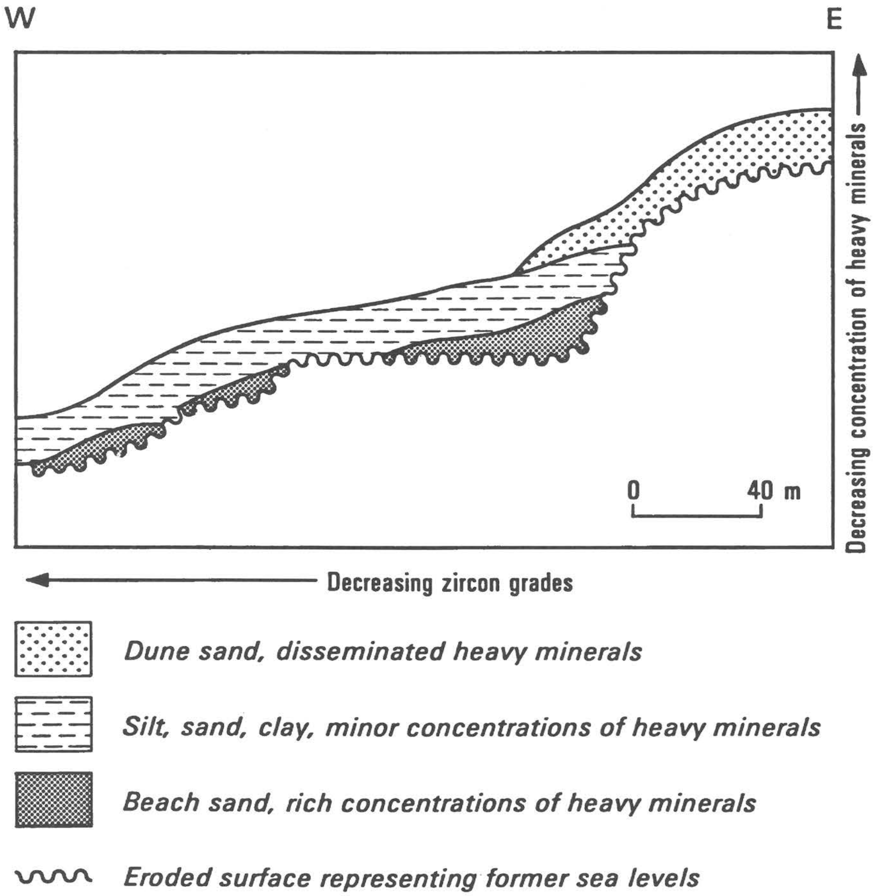


FIGURE 7. Schematic sketch of a buried placer deposit.

TABLE 5.—*Zirconium prospects, deposits, and districts not included in the International Strategic Minerals Inventory*

Name	Geologic deposit type	Comments
		BANGLADESH
Cox's Bazar-Maiskhal Island deposit	Placer	Zircon resource is 134,000 metric tons; no production as of 1989.
		EGYPT
Nile	Placer	Zircon resource is 420,000 metric tons; no production as of 1989.
		FEDERAL REPUBLIC OF GERMANY
Cuxhaven deposit	Placer	Zircon resource is 1,000,000 metric tons; no production as of 1989.
		INDIA
Ratnagiri district	Placer	No information on zirconium resources is available.
		KAMPUCHEA
Chamnop	Placer	Producing, but amount is unknown.
Chnuon	....do.........	Do.
Pailin	....do.........	Do.
Samlot	....do.........	Do.
Thmei	....do.........	Do.
		MALAYSIA
Perak-Selangor district	Placer, continental.	Zircon is extracted from tin tailings. No information on resources is available.
Lahat district	....do.........	Do.
		ROMANIA
Chituc	Placer	Producing, but amount is unknown.
Glogova-Sisesti district	....do.........	Contains 0.12 percent zircon undeveloped as of 1989.
		SIERRA LEONE
Gbangbama-Mogbemo district	Placer, continental.	No zircon production as of 1989.
		SOUTH KOREA
Asan Bay	Placer	No production.
Piin Beach	....do.........	Do.
Kosōng Beach	....do.........	Do.
		THAILAND
Phuket Province	Placer, continental.	Zircon is extracted from tin tailings.
Phang-nga	....do.........	Do.
Prachuab Khiri Khan	Placer	No information on zirconium resources is available (MacDonald, 1971).

TABLE 6.—*Zirconium resources in, and cumulative production from, the world's major zirconium deposits and districts, listed by geologic deposit type and resource category*

[Figures are based on data reported in table 14 of Part II and are in thousand metric tons of zirconium minerals, mainly zircon; figures in parentheses denote percentage of each mineral accounted for by each deposit type. N.r. = None reported]

Deposit type[1]	Number of records	Zirconium mineral	Resource category[2]		Cumulative production[5] (1925–87)
			R1E[3]	All other R1 and R2 resources[4]	
Placer	55	Zircon	37,293.8 (94.1)	21,091.9 (73.6)	15,423 (98.9)
Primary igneous deposits					
Magmatic	8	Zircon, baddeleyite, caldasite,[6] eudialyte	2,358.2 (5.9)	7,358.2 (25.7)	170 (1.1)
Volcanic	1	Gel-zircon	N.r.	193.2 (0.7)	N.r.
Total	64		39,652.0 (100)	28,643.3 (100)	15,593 (100)

[1] Deposit types of the world's major zirconium mineral deposits are shown in figure 3.
[2] Categories are defined in figure 1.
[3] Reliable estimates from identified deposits having economically exploitable resources (fig. 1).
[4] Includes resources in the R1M, R1S, R2E, and R2S categories (fig. 1).
[5] Cumulative production total differs from the total in table 10 because the data were obtained from different sources.
[6] Zirconium material from Brazil consisting of a mixture of fibrous baddeleyite, zircon, altered zircon, and other minerals (Heinrich, 1958, p. 125).

ZIRCONIUM RESOURCES

Total R1E resources in the world's major zirconium deposits and districts amount to some 39.7 million metric tons. The reported world total for "all other R1 and R2" resources (R1M, R1S, R2E, and R2S) is 28.6 million metric tons. These figures are based on data reported in table 14 of Part II. Table 6 shows the grouping of these resources and cumulative production according to geologic deposit type. Placer deposits, which contain the bulk of the zirconium resources, are 94 percent of R1E and about 74 percent of all other R1 and R2 resources. The remaining resources occur in magmatic deposits. About 99 percent of cumulative production of zirconium minerals has been from secondary placer deposits.

The distribution of the world's zirconium resources in major deposits and districts, listed by resource category and by country, is shown in table 7. South Africa, which has the largest share of these R1E zirconium resources, makes up 30 percent of the total, closely followed by Australia, which has 26 percent. The United States has 15, percent and India, Brazil, and Madagascar, about 8 percent each. Of the world's other R1 and R2 zirconium resources, Australia has the major share—30 percent of the total—followed by South Africa and Canada, which have about 24 percent each. Canada's reported resource of zirconium minerals is distributed in magmatic deposits (Thor Lake and Strange Lake). The United States has 10 percent of the total.

Distribution of the world's zirconium resources, listed by economic class of country, is shown in table 8 and in figure 8. Countries in each class are shown in figure 5. Industrial market economy countries have most of the major zirconium deposits and districts and a major share of both R1E and other R1 and R2 resources (41 percent and 70 percent respectively); Australia and the United States are the dominant countries in this economic class. The upper middle-income countries rank second in both resource categories, accounting for 12 major zirconium deposits and districts that contain 37 percent of R1E resources and 24 percent of resources in the other categories; South Africa is the dominant country in this class. Low-income countries, which have 11 deposits and districts, have 22 percent of the R1E resources; India and Madagascar are the major countries in the group.

There are no reported R1E resource figures for zirconium deposits in the eastern European nonmarket economy class represented by the Soviet Union and the unclassified economy class represented by Greenland. The lower middle-income countries have no reported zirconium deposits in the ISMI inventory. Table 6 indicates that total zirconium resources in the world's major deposits are many times greater than total reported cumulative production from these deposits. Using the

TABLE 7.—*Distribution of zirconium resources in the world's major deposits and districts, listed by country and resource category*

[Includes only countries having major zirconium minerals deposits and districts in the International Strategic Minerals Inventory. See figure 3. Figures are based on data as reported in table 14 of Part II and are in thousand metric tons of zircon (unless noted); figures may not add to totals shown due to rounding. Figures in parentheses are percent of resource category accounted for by each country. N.r. = None reported]

Country	Resource category[1]	
	R1E[2]	All other R1 and R2 resources[3]
AUSTRALASIA		
Australia	10,233.4 (25.8)	8,594.2 (30.0)
New Zealand	N.r.	1,436.0 (5.0)
NORTH AMERICA		
Canada	N.r.	7,000.0 (24.4)
Greenland	N.r.	312.0 (1.1)
United States	5,900.0 (14.9)	2,875.0 (10.0)
SOUTH AMERICA		
Brazil[4]	2,830.7 (7.1)	251.0 (0.9)
EUROPE		
Soviet Union[5]	N.r.	N.r.
AFRICA		
Madagascar	3,000.0 (7.6)	N.r.
Mozambique	316.8 (0.8)	N.r.
South Africa[5]	11,983.0 (30.2)	6,747.1 (23.6)
ASIA		
China	1,428.1 (3.6)	28.0 (0.1)
India	3,560.0 (9.0)	1,400.0 (4.9)
Sri Lanka	400.0 (1.0)	N.r.
Total	39,652.0 (100.0)	28,643.3 (100)

[1] Categories are defined in figure 1.

[2] Reliable estimates from identified deposits having economically exploitable resources.

[3] Includes resources in the R1M, R1S, R2E, and R2S categories.

[4] Includes baddeleyite and caldasite.

[5] Includes baddeleyite.

TABLE 8.—*Distribution of zirconium resources in the world's major deposits and districts, listed by economic class of country and resource category*

[Figures are in thousand metric tons of zirconium minerals, mainly zircon, and are based on data as reported in table 14 of Part II; figures may not add to totals shown due to rounding. Figures in parentheses are percent of column totals. N.r. = None reported]

Economic class[1]	Number of records	Resource category[2]	
		R1E	All other R1 and R2
Low-income	11	8,704.9 (22)	1,428.0 (5)
Upper middle-income.	12	14,813.7 (37)	6,998.1 (24)
Industrial market	37	16,133.4 (41)	19,905.2 (70)
Eastern European nonmarket.	3	N.r.	N.r.
Unclassified	1	N.r.	312.0 (1)
Total	64	39,652.0 (100)	28,643.3 (100)

[1] Based principally on GNP per capita and, in some instances, other distinguishing economic characteristics (World Bank, 1986, p. 180–181). Countries where major zirconium mineral deposits or districts occur are, by class: low-income economies—China, India, Madagascar, Mozambique, and Sri Lanka; upper middle-income economies—Brazil and South Africa; industrial market economies—Australia, Canada, New Zealand, and the United States; eastern European nonmarket economies—the Soviet Union; unclassified economies—Greenland. Two additional economic classes, lower middle-income economies and high-income oil exporters, are not listed because those countries do not have identified major zirconium mineral deposits.

[2] Categories are defined in figure 1.

estimate of R1E resources (table 6) and the rate of production in 1987 (table 9), world zirconium resources are about 46 times annual production.

The addition to world zirconium resources in major deposits through the discovery of new deposits is shown in figure 9. Some of the deposits, such as those at Barrytown and Westport in New Zealand, were discovered in the 19th century but have yet to produce zircon. These deposits were originally worked for alluvial gold. Likewise, the major discovery during the 1900–19 period was the Phalaborwa deposit, which was worked for copper; recovery of baddeleyite as a byproduct of copper mining did not commence until the early 1970's. Discoveries of major zirconium deposits and districts, during each of the following four 20-year periods, accounted for 70 to 75 thousand metric tons of zirconium minerals. Principal discoveries during these periods were 1920–39, the Chavara deposit in India, Pulmoddai deposit in Sri Lanka, and Trail Ridge deposit in the United States; 1940–59, North Stradbroke Island, Moreton Island, Fraser Island deposits, deposits along the Queensland coast of eastern Australia and deposits in the southwest of Western Australia, Chatrapur deposit in India, and Bothaville, Cape Morgan, and Transkei Coast

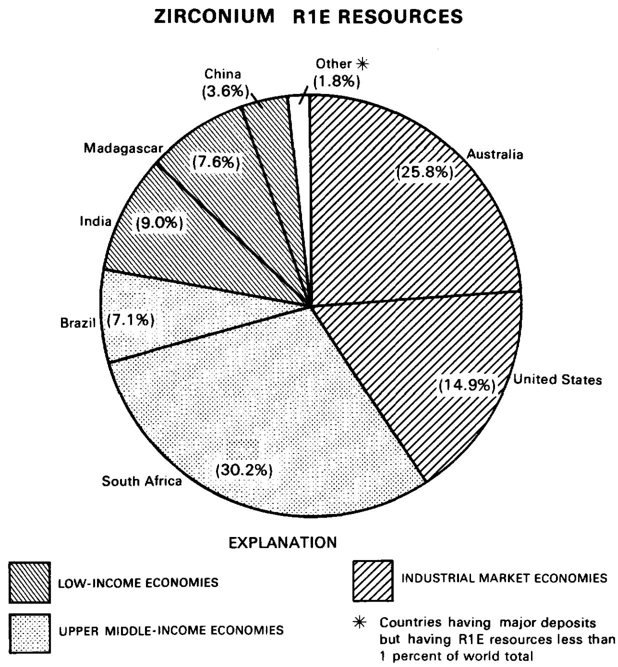


FIGURE 8. Distribution of zirconium identified economic resources in the world's major deposits and districts, shown by country and economic class of country.

TABLE 9.—*Annual (1987) and cumulative (1925–87) production of zirconium minerals, listed by country*

[Source of information: U.S. Bureau of Mines, 1926–90 and British Geological Survey, 1988. Figures are in thousand metric tons of zircon (unless noted); figures may not add to totals shown due to rounding. Figures in parentheses are percent of column totals.]

Country[1]	Annual production (1987)	Cumulative production (1925–87)
Australia	457 (53)	10,493 (67)
South Africa[2]	140 (16)	1,332 (8)
Soviet Union[2]	86 (10)	852 (5)
United States[3]	108 (13)	2,321 (15)
India	16 (2)	234 (1)
China	15 (2)	111 (1)
Brazil[4]	15 (2)	213 (1)
Sri Lanka	1 (0)	34 (0)
Madagascar	0 (0)	3 (0)
Mozambique	0 (0)	0 (0)
Other[5]	19 (2)	178 (1)
Total	857 (100)	15,772 (100)

[1] Includes all countries having major zirconium mineral deposits or districts in the International Strategic Minerals Inventory except for Canada, Greenland, and New Zealand, which had no reported zirconium mineral production for the years 1925 through 1987.

[2] Figures include baddeleyite.

[3] Majority of United States' zircon production figures withheld; figures are estimates calculated from available data.

[4] Figures include caldasite and some baddeleyite.

[5] Countries having zircon deposits but not included in the zircon inventory (in order of importance): Malaysia (current producer), Thailand (current producer), Senegal, Nigeria, Egypt, and South Korea.

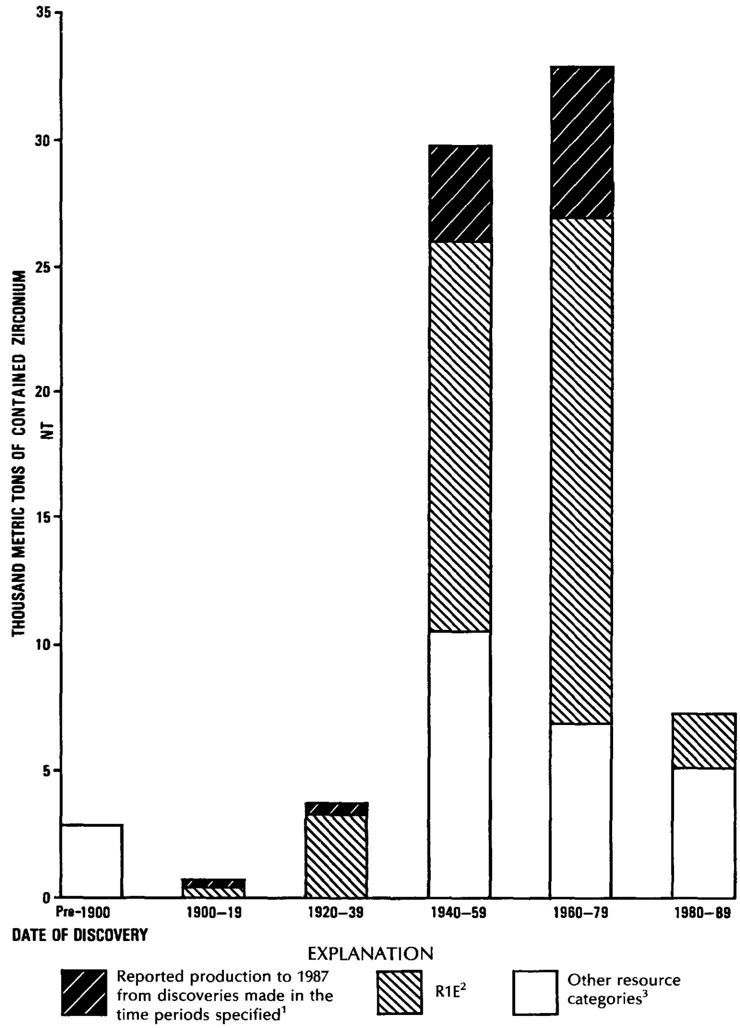
deposits in South Africa; 1960–79, the Eneabba deposits in Western Australia, Tomago-Viney Creek deposits in New South Wales, North Natal Coast deposit of South Africa, and Green Cove Springs deposit in the United States; 1980 to present, WIM–150 deposit in Australia and Pitinga deposit in Brazil, which is essentially a tin producer.

During the 1960–79 period, a number of magmatic sources of zirconium minerals were discovered. These included the Brockman deposit in Australia, the Strange Lake and Thor Lake deposits in Canada, the Ilimaussaq deposit in Greenland, and probably the Lovozero deposit in the Soviet Union. None of these deposits are producing zirconium minerals.

Conclusions drawn from figure 9 should take account of (1) the uncertainty of discovery dates due to difficulties in defining what a "discovery" is, (2) the limited validity of assigning all of a deposit's (or district's) resources to the initial discovery date, as done in figure 9, and (3) the different standards used by different countries to report resource data. The relatively smaller amount of resources contained in discoveries made since 1980 may merely reflect incomplete information about the resources of recently discovered deposits and the time lag in reporting information about new discoveries. The smaller amount of resources may also reflect the lower zirconium content in many of the new mineral-sand deposits that have been discovered as a result of the increased exploration since the early 1980's.

ZIRCONIUM MINERAL PRODUCTION

The 64 zirconium deposits and districts in the International Strategic Minerals Inventory occur in 13 countries; these countries together have accounted for most of the world's zirconium mineral production since 1925. Cumulative world production of zirconium minerals in the period 1940 through 1987 was 15.77 million metric tons (U.S. Bureau of Mines, 1988, and British Geological Survey, 1988). More than 98 percent of this total is accounted for by the countries listed in the inventory. World production in 1987 was 837,590



[1] The production shown for deposits and districts in the inventory is about 9.87 million metric tons. Cumulative production from countries having deposits in the inventory for the same period (1925–1987) as reported by the sources listed in table 9 is 15.77 million metric tons. The difference (5.91 million metric tons) is because not all production is directly attributable to the specific deposits in the inventory and because the national production totals include deposits that are not in the inventory.

[2] Defined as reliable estimates from identified deposits with economically exploitable resources (fig. 1).

[3] Includes resources in the R1M, R1S, R2E, and R2S categories (fig. 1).

FIGURE 9. Zirconium resources in the world's major deposits and districts according to their date of discovery.

metric tons of zirconium minerals. Table 9 and figures 10 and 11 show the production of zirconium minerals, listed by individual countries. The data plotted in figure 10 include a small amount of production from mines that are not in the inventory.

From 1940 to 1970, the average increase per decade in world production exceeded 230 percent, but between 1970 and 1980 the increase was only 53 percent. From 1980 to 1987, zirconium mineral production increased by only 13 percent. This is in contrast to titanium mineral production; for the period 1980–87, ilmenite production increased by only about 5 percent, and rutile production decreased by 3 percent (Towner and others, 1988; Towner, 1989). Several important

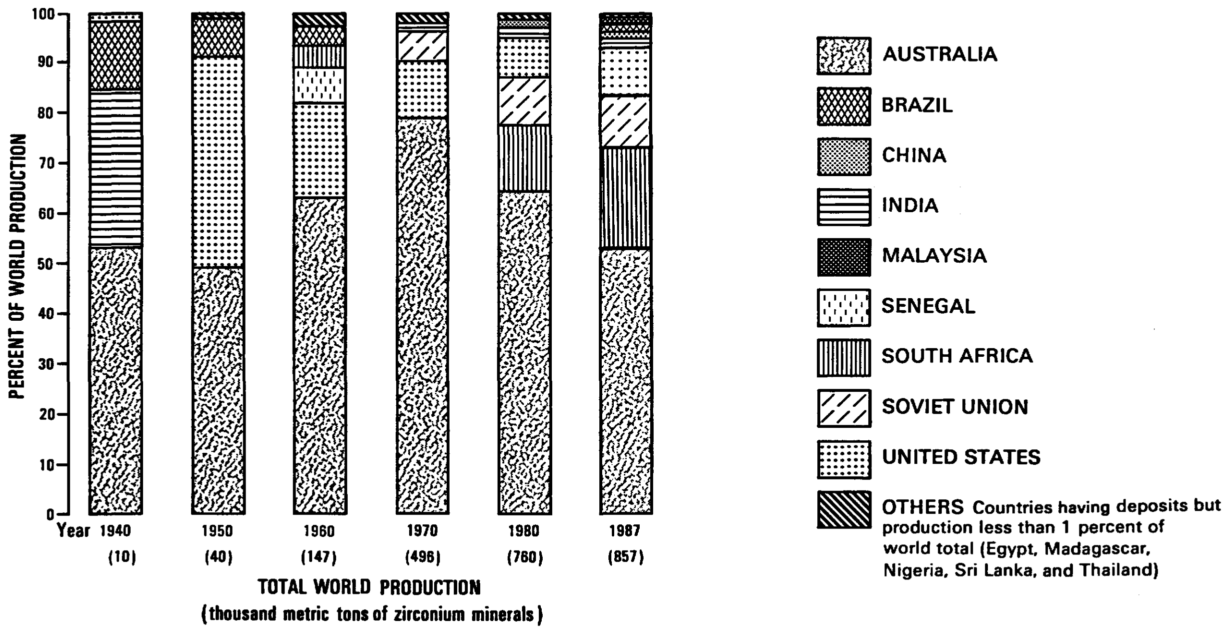


FIGURE 10. Distribution of world production of zirconium minerals, shown by country for selected years 1940–87 (U.S. Bureau of Mines, 1942–88). Note that, for 1987, revised production figures for South Africa and the United States (see table 9) have not been included.

conclusions can be drawn from the patterns of world zirconium-mineral production shown in figures 10 and 11.

- Australia has been a dominant producer since 1940. In 1970 Australia accounted for about 80 percent of world production and is by far the dominant current producer, having produced 457,000 metric tons in 1987 (53 percent of world output). By 1980, South Africa emerged as a major zirconium mineral producer—its share of world production is increasing (19 percent in 1987)—followed by (about 10 percent each) the United States, which ranked second as a zirconium producer from 1950 to 1970, and the Soviet Union, which also emerged as an important producer and for which there are no reliable published production data.
- From 1940 to 1987, world production of zirconium increased from 10,000 metric tons per year to 857,000 metric tons per year or about 86 times.
- India and Brazil ranked second and third, respectively, after Australia as major zirconium mineral producers in 1940, but both are now relatively minor producers.
- Senegal was the third largest producer in 1960 after Australia and the United States but has recorded no production since that time.

Information on 1987 production and cumulative production from 1925 to 1987 for countries having deposits in the inventory is shown in table 9. These production data have been grouped by World Bank economic class in table 10. About 65 percent of 1987 production and 81 percent of cumulative production since 1925 came from industrial market economy countries (principally Australia and the United States). The upper middle-income economy countries (notably South Africa) and the eastern European nonmarket economy class (the Soviet Union) follow the industrial market economy class in amount of annual and cumulative zirconium production.

Zirconium minerals are produced only from surface mining operations. Table 11 shows the distribution of resources according to mining method and economic class of country. Reported cumulative production of zirconium from the world's major deposits currently in production, according to geologic type, is shown in table 6. Nearly 99 percent of cumulative production has come from placer deposits. An insignificant amount, principally of baddeleyite and some minor caldasite, has been produced from magmatic deposits.

In studies of the structure of industrial markets, one way of measuring market concentration is to focus directly on observable dimensions, such as numbers of

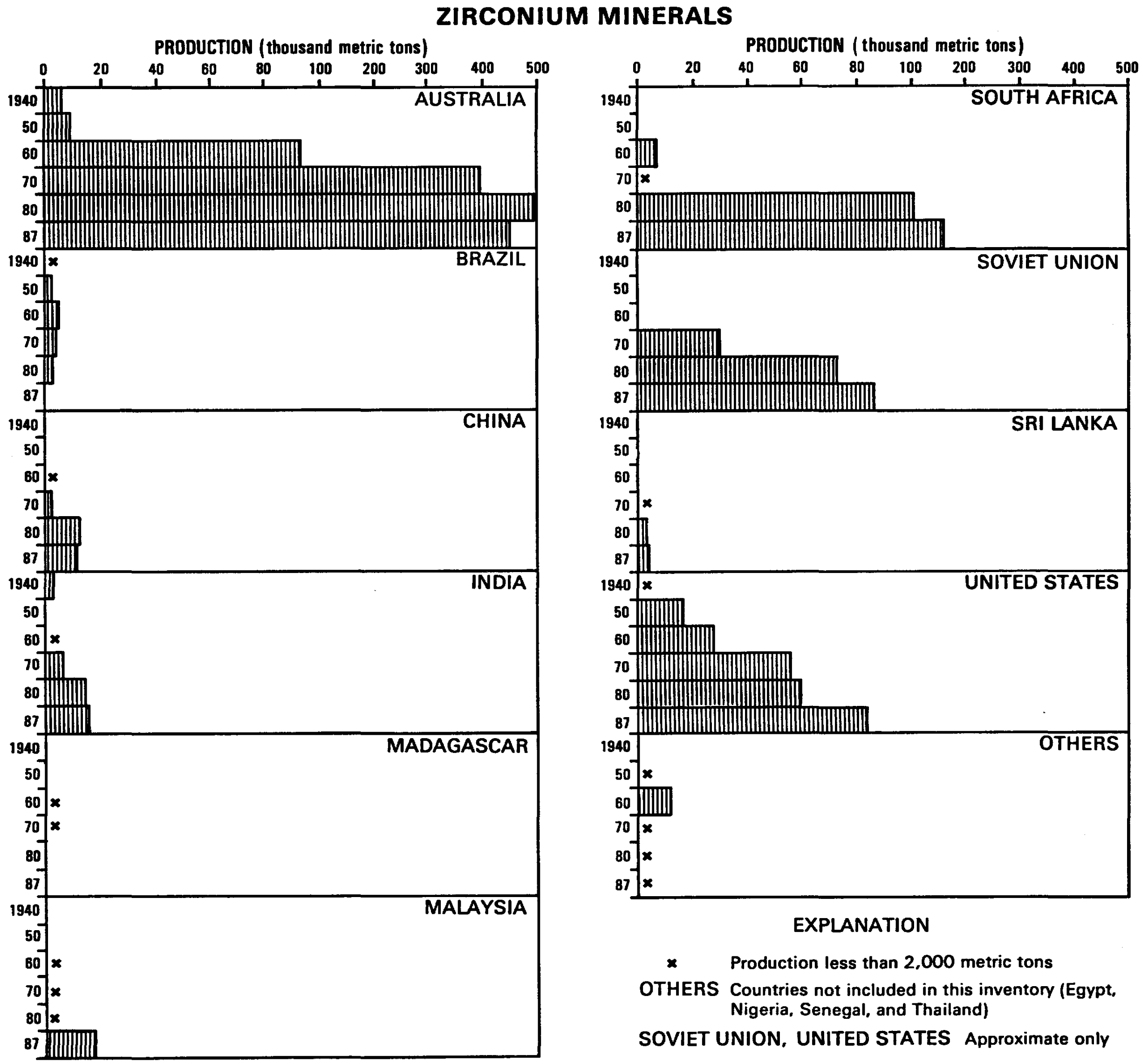


FIGURE 11. Zirconium mineral production, shown by country for selected years 1940–87 (U.S. Bureau of Mines, 1942–88). Note that, for 1987, revised production figures for South Africa and the United States have not been included.

suppliers. The market concentration ratio, defined as the percentage of total industry sales or output contributed by the largest few firms (Scherer, 1970, p. 50–51), can be used for countries as well. Figure 12 shows the four- and eight-country concentration ratios for 1913 and 1980 production for several nonfuel mineral commodities. By these measures, zirconium ranked high among those mineral commodities controlled by a few producing countries in 1913. This concentration of zirconium production declined slightly from 1913 to 1980, from 100 to about 96 percent based on the four-country ratio. The top eight producing countries accounted for 100 percent of zirconium production in 1913 and in 1980.

Country concentration provides only a rough measure of industry (company) competition because it understates concentration of ownership in cases where a few companies have large production capacities in different countries. For example, AMC Mineral Sands Ltd., a wholly owned subsidiary of Renison Consolidated Goldfields Ltd., produces about 40 percent of the world's zirconium-mineral output from operations in Australia and the United States, and Richards Bay

TABLE 10.—*Annual (1987) and cumulative (1925–87) production of zirconium minerals, listed by economic class of country*

[Figures are calculated from reported production figures (U.S. Bureau of Mines, 1926–90; British Geological Survey, 1988) and are in metric tons of zirconium minerals, mainly zircon; figures may not add to totals due to rounding. Figures in parentheses denote percentage of world total. N.r. = None reported]

Economic class[1]	Actual production (1987)	Cumulative production[2] (1925–87)
Low-income	32,000 (3.8)	381,713 (2.4)
Lower middle-income	N.r.	67,262 (0.4)
Upper middle-income	178,000 (21.3)	1,656,708 (10.5)
Industrial market	541,590 (64.7)	12,813,796 (81.2)
Eastern European nonmarket.	86,000 (10.3)	852,100 (5.4)
Total	837,590 (100)	15,771,579 (100)

[1] Based principally on GNP per capita and, in some instances, other distinguishing economic characteristics (World Bank, 1986, p. 180–181 and 243). Countries where major zirconium mineral deposits or districts occur are shown in figure 3. Also includes minor production for the following countries not included in the inventory (in order of importance): Malaysia and Thailand (both current producers), Senegal, Nigeria, Egypt, and South Korea. Two other economic classes, lower middle-income economies and high-income oil exporters are not listed because those countries do not have identified major zirconium mineral deposits. The unclassified economies class is not listed because Greenland is not a zirconium mineral producer.

[2] Cumulative production total differs from the total in tables 6 and 11 because the data were obtained from different sources.

TABLE 11.—*Zirconium resources in the world's major deposits and districts, listed by mining method and economic class of country, and zirconium mineral cumulative production, listed by mining method*

[Resources include those in R1 and R2 categories (figure 1); figures are based on data as reported in table 14 of Part II and are in thousand metric tons of zirconium minerals, mainly zircon; figures may not add to totals shown due to rounding. N.r. = none reported]

Economic class[1]	Mining method[2]	
	Surface	Never mined
Low-income	10,132.9	N.r.
Upper middle-income	17,032.7	4,779.1
Industrial market	16,110.8	14,382.8
Eastern European nonmarket	N.r.	N.r.
Unclassified	N.r.	N.r.
Total	43,276.4	19,161.9
Cumulative production (1925–87)[3]	15,592.7	N.r.

[1] Based principally on GNP per capita and, in some instances, other distinguishing economic characteristics (World Bank, 1986, p. 180–181). Countries where major zirconium mineral deposits or districts occur are, by class: low-income economies—China, India, Madagascar, Mozambique, Sri Lanka; upper middle-income economies—Brazil and South Africa; industrial market economies—Australia, Canada, New Zealand, and the United States; eastern European nonmarket economies—Soviet Union; unclassified economies—Greenland. Two additional economic classes, lower middle-income economies and high-income oil exporters, are not listed because those countries do not have identified major zirconium mineral deposits.

[2] None of the deposits or districts in the ISMI zirconium inventory have reported resources that are being mined by underground methods.

[3] Cumulative production total differs from the total in table 6 because the data were obtained from different sources.

Minerals of South Africa produces about 20 percent from its North Natal Coast deposit near Richards Bay.

Present and probable future production of zirconium minerals from the major deposits and districts included in the International Strategic Minerals Inventory are shown in the map in figure 13. Present major producers (Australia and South Africa) will continue to be significant producers to the year 2020. The source of South Africa's production will continue to be from the North Natal Coast deposit; depletion of certain deposits in Australia (particularly Eneabba and North Stradbroke Island) will probably be compensated for by production from new deposits at Cooljarloo, WIM–150, and Bayfield. In low-income economy countries, deposits such as those in the Pebane district, Mozambique; Taolanaro, Madagascar; and Chavara, India, may become important sources of zirconium minerals in the future so that the four- and eight-country concentration ratios for zirconium minerals may decline further. U.S. production, currently ranked fourth, may decline further as deposits at Trail Ridge and Green Cove Springs become exhausted. This decline, however, could be offset by production from Soledad Canyon district, which has large zircon resources. It is unlikely that any of the newly discovered magmatic deposits containing large resources of zirconium minerals (for example in Canada, and in the Soviet Union) will become major sources of these minerals before 2020. These forecasts do not take into account the possible discovery of new deposits or the possible effects of technological advances on the economics of mining known deposits or of supply and demand changes.

ZIRCONIUM TRADE

Because the United States and the Soviet Union consume the bulk of their own output, world export trade of zircon is dominated by Australia and South Africa. A

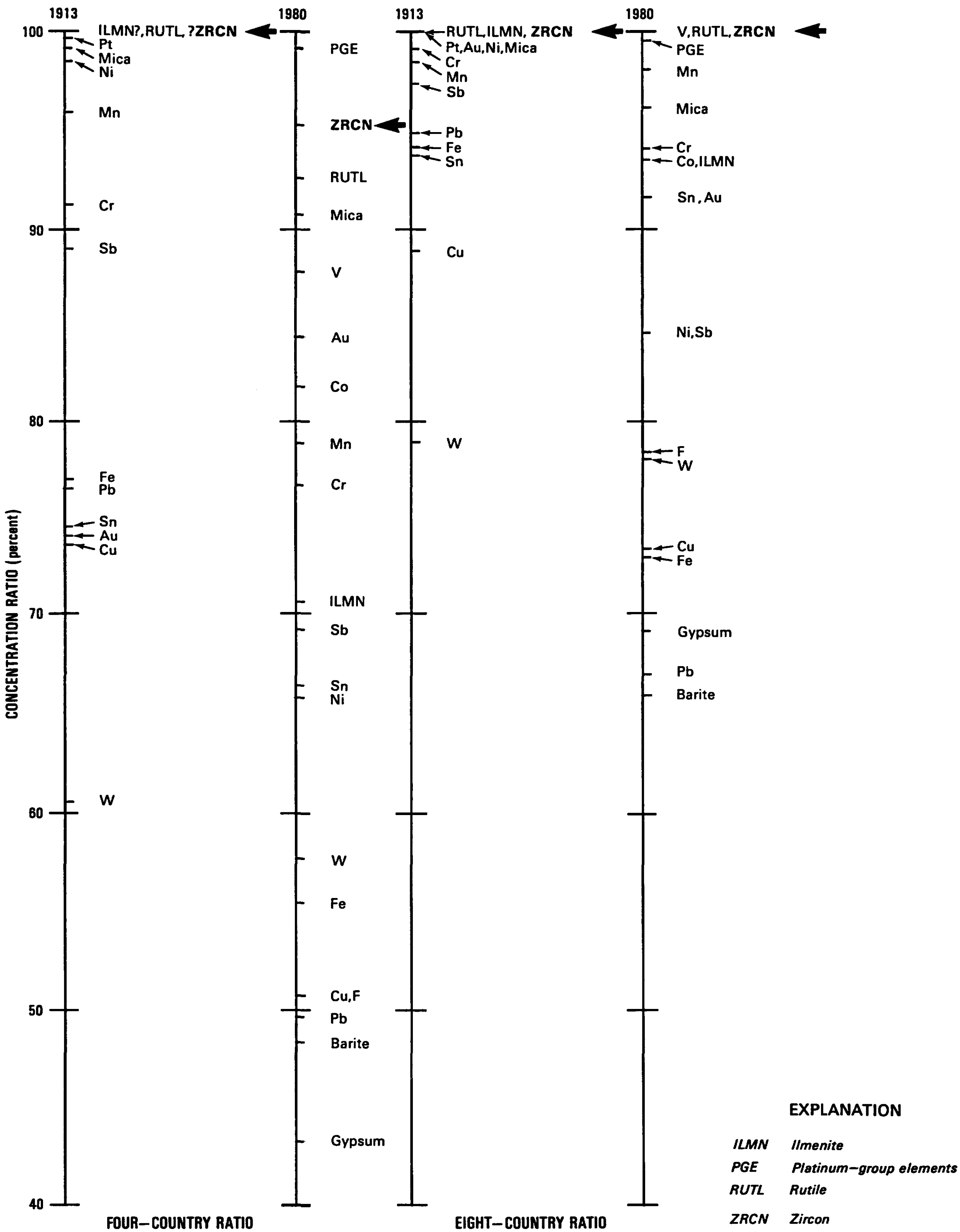
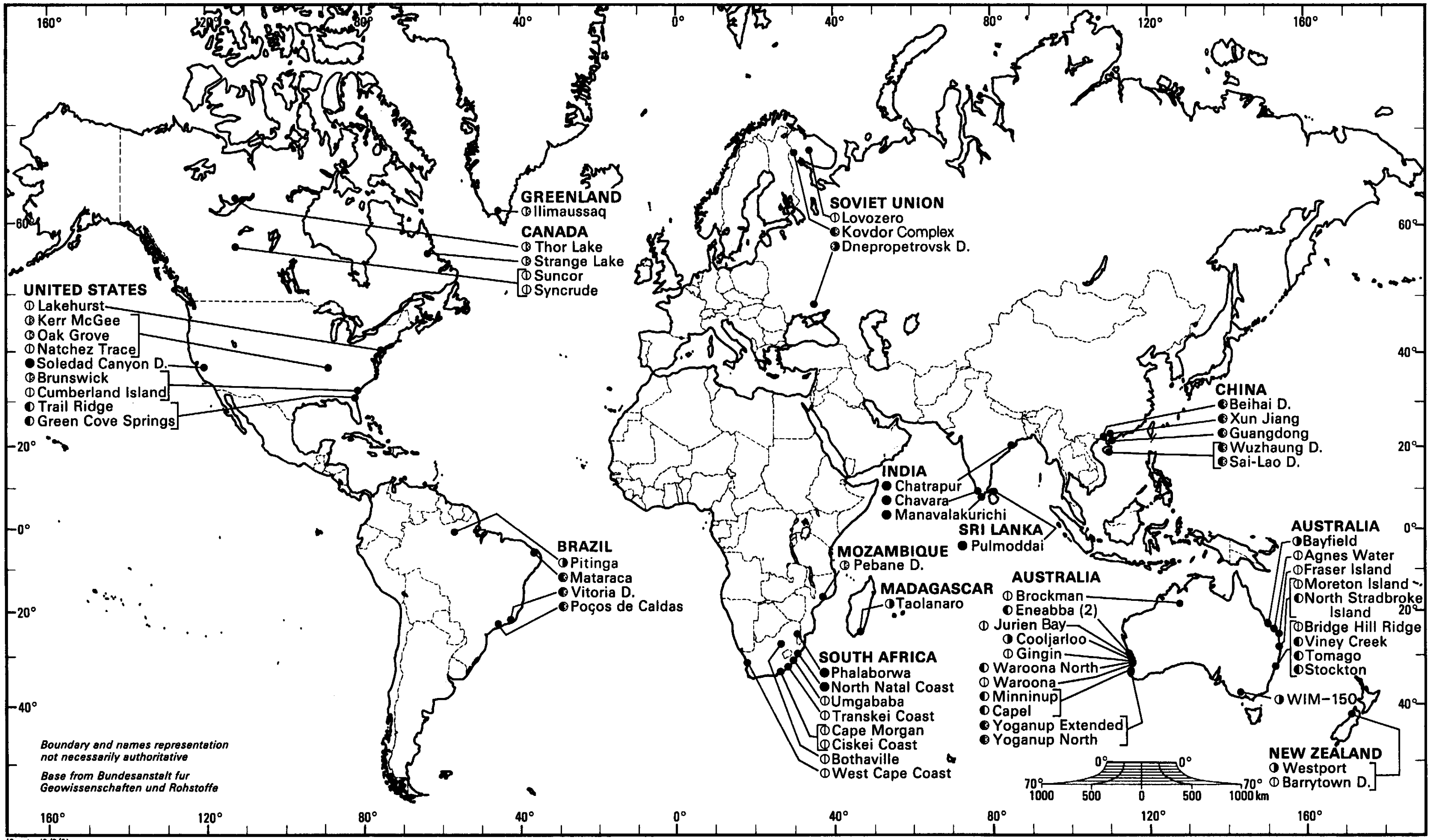


FIGURE 12. Concentration ratios for selected nonfuel mineral commodity production in 1913 and 1980.



D. District

- ● Producer in 1987; probably a significant producer in 2020
- ◐ Producer in 1987; probably an insignificant producer or exhausted by 2020
- Producer in 1987; information insufficient to permit any forecast as to future production
- ◑ No production in 1987; probably a significant producer in 2020
- No production in 1987; probably an insignificant producer or no production in 2020
- No production in 1987; information insufficient to permit any forecast as to future production

FIGURE 13. Major zirconium mineral deposits and districts, their present production status, and their probable production status in 2020. Number in parentheses (following Eneabba, Australia) indicates the number of records (deposits or districts). Location names are from tables 13 and 14 in Part II.

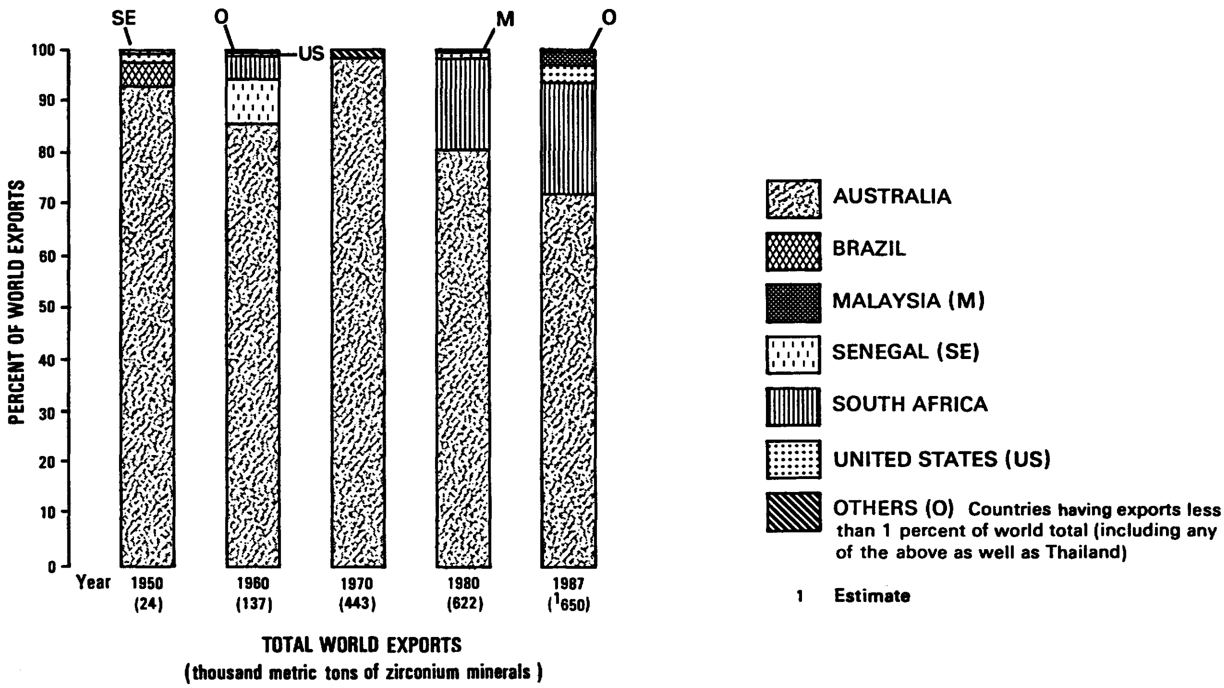


FIGURE 14. Distribution of world exports of zirconium mineral concentrates, listed by country for selected years 1950–87 (British Geological Survey, 1940–87).

substantial volume of zircon is also reexported from the Netherlands and West Germany to other European destinations. Figure 14 shows the proportion of total world exports of zirconium minerals by individual country for selected years 1950–87 and table 12 provides details of countries importing zircon and sources of their consignments for 1983 through 1989. In 1987, Australia exported 465,103 metric tons representing all of its production plus stock; South Africa is reported to have exported all of its production.

The level and pattern of consumption of zircon vary considerably from country to country. Japan is the world's leading importer and consumer of zircon, most of which is consumed in refractories, principally for ladle linings and continuous steel-casting nozzles, and the remainder is used mostly in ceramics and foundries. In the United States, the second largest zircon consumer, the emphasis still remains on foundry applications (table 3). In Italy, however, where imports reached nearly 85,000 metric tons in 1985, the largest market is ceramics. While the foundry industry is the largest consumer of zircon, it is also the most price sensitive so that as prices increased during 1987 some substitution by lower priced materials, such as olivine and chromite, occurred.

CONCLUSIONS

Zirconium is a widely distributed element, but commercial concentrations are confined to only two minerals, zircon and baddeleyite. Zircon is important in the steel industry for its high fusion point, low thermal expansion, and high thermal conductivity. Zirconia, in its natural form (baddeleyite) or manufactured from zircon, is valued in ceramic applications, abrasives, and refractories. Hafnium-free zirconium is used for sheathing fuel elements in nuclear reactors. About 95 percent of world zirconium mineral output is consumed in refractory, foundry, and ceramic applications.

Identified world economic zirconium resources (R1E category) in major deposits and districts listed in the ISMI zirconium inventory total about 40 million metric tons and are located mainly in South Africa, Australia, and the United States. Recent (1987) world mine production of zirconium minerals from countries that have major deposits or districts is about 857,000 metric tons; about 72 percent of this comes from two countries, Australia and South Africa. Two other countries, the United States and the Soviet Union, contribute another 20 percent. Consequently, many industrialized nations do not have enough zirconium minerals from

TABLE 12.—*Major zircon-importing countries and the sources of their imports for 1983–89*

[Source: British Geological Survey, 1989, and data files. Figures are in metric tons of zirconium minerals, mainly zircon. N.a. = not available. —, no data]

Source of imports	1983	1984	1985	1986	1987	1988	1989
FEDERAL REPUBLIC OF GERMANY							
Argentina	500	—	—	—	—	N.a.	N.a.
Australia	30,768	37,394	31,511	38,153	31,588	N.a.	N.a.
China	—	—	1,107	—	—	N.a.	N.a.
Netherlands	1,126	1,913	4,610	5,596	1,026	N.a.	N.a.
South Africa	26,683	34,456	38,248	28,296	21,786	N.a.	N.a.
Sri Lanka	6,465	1,102	980	2,160	275	N.a.	N.a.
United States	2,191	74	1,724	5,786	2,426	N.a.	N.a.
Others	889	547	749	3,011	1,794	N.a.	N.a.
Total	68,622	75,486	78,929	83,002	58,895	[1]57,237	N.a.
FRANCE							
Australia	23,914	27,354	43,248	30,627	41,763	38,100	N.a.
Federal Republic of Germany	346	359	426	527	410	531	N.a.
South Africa	10,246	7,833	6,820	6,574	5,849	4,800	N.a.
United States	214	879	690	684	141	579	N.a.
Others	215	199	121	520	957	1,751	N.a.
Total	34,935	36,624	51,305	38,932	49,120	45,761	52,104
ITALY							
Australia	44,722	53,444	71,375	36,851	63,469	N.a.	N.a.
Federal Republic of Germany	967	517	—	281	—	N.a.	N.a.
South Africa	28,487	16,921	12,786	10,823	10,225	N.a.	N.a.
Others	859	217	466	220	4,540	N.a.	N.a.
Total	75,035	71,099	84,627	48,175	78,234	82,863	84,814
JAPAN							
Australia	160,417	183,799	198,511	151,762	159,096	153,683	N.a.
India	1,000	500	630	0	—	—	N.a.
Malaysia	1,674	1,206	1,152	1,356	1,360	10,675	N.a.
South Africa	31,031	25,345	30,906	18,513	15,865	24,790	N.a.
Sri Lanka	4,088	3,629	500	34	—	—	N.a.
United States	14	3,169	6,620	24	1,153	4,941	N.a.
Others	0	0	2	20	0	3,503	N.a.
Total	198,224	217,648	238,321	171,709	177,474	197,592	172,848
NETHERLANDS							
Australia	12,276	36,421	25,393	28,037	16,899	9,377	N.a.
Federal Republic of Germany	410	510	485	293	562	496	N.a.
South Africa	11,364	8,222	10,910	8,487	11,415	13,341	N.a.
Sri Lanka	1,910	—	3,937	—	—	—	N.a.
Others	116	271	131	1,647	1,051	4,493	N.a.
Total	26,076	45,424	40,856	38,464	29,927	27,707	45,504
SOUTH KOREA							
Australia	1,615	5,751	5,260	8,719	13,688	14,808	N.a.
Japan	77	380	142	411	184	104	N.a.
Malaysia	768	912	457	774	1,591	444	N.a.
Others	54	54	69	940	3,539	9,074	N.a.
Total	2,514	7,097	5,928	10,844	19,002	24,430	21,813
SPAIN							
Australia	9,022	18,220	20,204	11,004	17,041	N.a.	N.a.
South Africa	8,546	16,445	16,945	14,738	16,240	N.a.	N.a.
Others	70	244	61	71	2,019	N.a.	N.a.
Total	17,638	34,909	37,210	25,813	35,300	42,646	N.a.

TABLE 12.—*Major zircon-importing countries and the sources of their imports for 1983–89*—Continued

Source of imports	1983	1984	1985	1986	1987	1988	1989
			UNITED KINGDOM				
Australia	18,035	18,220	24,206	19,823	22,216	26,504	N.a.
South Africa	8,186	16,445	21,045	12,819	2,684	14,309	N.a.
Others	11,183	8,412	3,576	633	12,408	2,598	N.a.
Total	37,404	43,077	48,827	33,275	37,308	43,411	55,228
			UNITED STATES				
Argentina	—	—	5,261	8,104	—	—	N.a.
Australia	32,786	40,111	22,088	37,256	50,642	52,929	N.a.
Canada	1,066	1,316	2,093	669	—	—	N.a.
South Africa	6,399	18,424	9,842	22,588	16,964	23,281	N.a.
Others	107	420	440	147	312	122	N.a.
Total	40,358	60,271	39,724	68,764	67,918	76,332	73,129

[1] Includes niobium and tantalum ores.

domestic sources to satisfy their demand and must rely on imports. The United States, for example, had an average annual mine production of only 63,000 metric tons per year of zircon from 1976 to 1986 and imported, on average, 76,000 metric tons per year of zircon during that period to satisfy domestic demand (about 141,300 metric tons per year) and to maintain stocks (U.S. Bureau of Mines, 1978–89). In 1988, United States production was 117,000 metric tons.

Major deposits of zirconium minerals are classified into two geologic types: secondary placer deposits and primary igneous deposits. About 99 percent of cumulative world production of zirconium mineral production has been from placer deposits, especially from those in Australia. Some 97 percent of R1E resources are also represented by placer deposits.

In 1986, the world zirconium mineral market was affected by a supply shortage that continues to the present (1988). This shortage was caused by declining ore grades and accentuated by strong demand for zirconium minerals in the refractory and ceramics industries. The shortage has led to higher prices, which, in turn, has led to substitution, particularly by chromite in the foundry industry. The shortfall could persist until new deposits in Australia, India, and Madagascar begin producing.

The ISMI zirconium inventory's mineral-resource data, together with projected production levels, suggest that the pattern of world production may not be substantially different by the year 2020. By then, Australia and South Africa should still be dominant producers, although their shares of world output could decrease. Production from Madagascar, Brazil, Mozambique, and India could, by then, account for a substantial proportion of world output. However, because of the dynamic nature of mineral resources, this scenario could change depending on new discoveries and (or) the effects of technological changes on supply and demand of zirconium minerals.

PART II—SELECTED INVENTORY INFORMATION FOR ZIRCONIUM DEPOSITS AND DISTRICTS

Tables 13 and 14 contain information from the International Strategic Minerals Inventory record forms for zirconium deposits and districts. Only selected items of information about the geology and location (table 13) and mineral production and resources (table 14) of the deposits are listed here; some of this information has been abbreviated.

Summary descriptions and data are presented in the tables essentially as they were reported in the inventory records. For instance, significant digits for amounts of production or resources have been maintained as reported. Data that were reported in units other than metric tons have been converted to metric tons for comparability. Some of the data in the tables are more aggregated than in the inventory records, such as cumulative production totals that for some mines have been reported by year or by groups of years. Some of the abbreviations used in the inventory record forms have been used in these tables; they are explained in the headnotes.

TABLE 13.—*Selected geologic and location information*

Abbreviations used throughout this table include
- —, not reported on the ISMI record form
- Fm, formation
- Ma, million years
- asl, above sea level
- avg, average

Host rock includes all or some of the following items (separated by semicolons): main host rock type; formation name; and host rock age.
Age abbreviations and prefixes:

Cenozoic	CEN	Tertiary	TERT	Permian	PERM	Archean	ARCH
Quaternary	QUAT	Pliocene	PLIO	Carboniferous	CARB	Late	L
Holocene	HOLO	Miocene	MIO	Devonian	DEV	Middle	M
Pleistocene	PLEIS	Cretaceous	CRET	Proterozoic	PROT	Early	E

Site name	Latitude	Longitude	Deposit type	Host rock	Age of mineralization
			AUSTRALIA		
EAST COAST					
Agnes Water deposit	24°13′S.	151°54′E.	Placer, marine	Aeolian sand; QUAT	QUAT
Bayfield deposit	22°48′S.	150°46′E.	....do.........	....do.........	LTERT-QUAT
Bridge Hill Ridge deposit	32°25′S.	152°28′E.	....do.........	....do.........	....do.........
Fraser Island	25°22′S.	153°07′E.	....do.........	Sand; LTERT-QUAT	....do.........
Moreton Island	27°11′S.	153°24′E.	....do.........	....do.........	....do.........
North Stradbroke Island	27°35′S.	153°27′E.	....do.........	....do.........	....do.........
Stockton deposit	32°50′S.	151°51′E.	....do.........	Sand; HOLO	HOLO
Tomago deposit	32°48′S.	151° 43′E.	....do.........	Sand; PLEIS	PLEIS
Viney Creek deposit	32°40′S.	152°10′E.	....do.........	Sand; QUAT	QUAT
WIM–150 deposit	36°43′S.	142°12′E.	....do.........	Sand; EPLIO	EPLIO
WEST COAST					
Brockman deposit	18°19′S.	127°46′E.	Volcanic, other	Volcanic tuff; Upper Brockman Tuff	EPROT

from ISMI records for zirconium deposits and districts

Abbreviations for mineral names (after Longe and others, 1978, p. 63–66):

Aegirine . . . . . AGRN	Chalcopyrite . . . . . CLCP	Hornblende . . . . . HBLD	Rare earth oxides . . . . . REO
Albite . . . . . ALBT	Clay . . . . . CLAY	Ilmenite . . . . . ILMN	Rinkite . . . . . RNKT
Allanite . . . . . ALNT	Columbite . . . . . CLMB	Kainosite (senosite) . . . . . KNST	Rutile . . . . . RUTL
Arfvedsonite . . . . . AFVD	Cubanite . . . . . CBNT	Kyanite . . . . . KYNT	Sillimanite . . . . . SLMN
Anatase . . . . . ANTS	Elpidite . . . . . ELPD	Leucoxene . . . . . LCXN	Staurolite . . . . . STRL
Apatite . . . . . APTT	Eudialyte . . . . . EDLT	Magnetite . . . . . MGNT	Steenstrupine . . . . . STST
Armstrongite . . . . . ARMS	Feldspar . . . . . FLDP	Microcline . . . . . MCCL	Tantalite . . . . . TNTL
Baddeleyite . . . . . BDLT	Fluorite . . . . . FLRT	Monazite . . . . . MNZT	Tourmaline . . . . . TRML
Bastnaesite . . . . . BSNS	Forsterite . . . . . FRSR	Naujakasite . . . . . NJKS	Uranothorite . . . . . URNR
Biotite . . . . . BOTT	Gadolinite . . . . . GDLN	Nepheline . . . . . NPLN	Vallerite . . . . . VLRT
Bornite . . . . . BRNT	Garnet . . . . . GRNT	Perthite . . . . . PRTT	Vermiculite . . . . . VMCL
Caldasite . . . . . CLDT	Gittinsite . . . . . GTTN	Pyrite . . . . . PYRT	Xenotime . . . . . XNTM
Cassiterite . . . . . CSTR	Heavy minerals . . . . . HM	Pyrochlore . . . . . PCLR	Zircon . . . . . ZRCN
Chalcocite CLCC	Hematite . . . . . HMTT	Quartz . . . . . QRTZ	

Tectonic setting	Local environment	Principal mineral assemblages	Comments	Reference
		AUSTRALIA—Continued		
Basin	Dune, beach	ZRCN, ILMN, RUTL, MNZT; QRTZ	Dune deposits, HM grade: 1–8 percent; HM content: ILMN–72 percent, ZRCN–16 percent.	Mineral Deposits Ltd. (1978).
....do.........	....do.........	ZRCN, ILMN, RUTL; QRTZ	Dune deposits with an avg grade of 1.14 percent HM.	—
....do.........	....do.........	ZRCN, RUTL, ILMN, MNZT; QRTZ	Dune deposits with an avg grade of 0.12–0.19 percent ZRCN.	Australian Business (1985); Coffey and Hollingsworth Pty. Ltd. (1973).
....do.........	....do.........	ZRCN, RUTL, ILMN; QRTZ	Dune and beach deposits	Australian Government (1976).
....do.........	....do.........	ZRCN, RUTL, ILMN; QRTZ	Dune and beach deposits. Avg grade: 0.98 percent HM; ZRCN content 15.3–19.6 percent of HM.	Cook and others (1977).
....do.........	Dune	RUTL, ZRCN, ILMN, MNZT; QRTZ	Majority of resources are in low-grade sand dunes. Grade at Bayside deposit is 1.5 percent HM with 0.3 percent ZRCN.	Australian Business (1985); Consolidated Rutile Ltd. (1986).
....do.........	Dune, beach	RUTL, ZRCN, ILMN, MNZT; QRTZ	Two distinct orebodies; western dunes and eastern beach; 2 km inland.	Mineral Deposits Ltd. (1977).
....do.........	....do.........	ZRCN, RUTL, ILMN, MNZT; QRTZ	Ore occurs as lens-shaped bodies over distance of 15 km. Avg grade 1.5–2.0 percent HM; ZRCN content is 46 percent of HM.	James B. Crofts and Associates Pty. Ltd. (1983).
....do.........	Beach	RUTL, ZRCN, ILMN; QRTZ	Two mineralized zones; avg grade 0.8 percent HM.	R.W. Corkery and Co. Pty. Ltd. (1985).
Beach	Strandplain	ZRCN, RUTL, ILMN, ANTS, LCXN, MNZT, XNTM; QRTZ.	Sequence of 15 m of very fine sands. Avg grade: 2 percent HM.	Brown and Stephenson (1991).
Mobil belt	Stratabound	CLMB,Ta-CLMB, PCLR, ZRCN, BSNS, XNTM, CSTR	Mineralized zone 2–30 m thick, strike length 2.8 km. Ore mineralogy is fine grained.	Roberts (1988).

TABLE 13.—*Selected geologic and location information from ISMI*

Site name	Latitude	Longitude	Deposit type	Host rock	Age of mineralization
			AUSTRALIA—Continued		
WEST COAST—Continued					
Capel (AMC) deposit	33°33′S.	115°33′E.	Placer, marine	Sand; Bassendean Sand; EPLEIS	PLEIS
Cooljarloo deposit	30°40′S.	115°20′E.	....do.........	Sand; Bassendean Sand, Yoganup Fm; EPLEIS	....do.........
Eneabba (Allied) deposit	29°54′S.	115°16′E.	....do.........	Sand; LTERT-PLEIS	LTERT-PLEIS
Eneabba (AMC) deposit	29°47′S.	115°19′E.	....do.........	....do.........	....do.........
Gingin deposit	31°17′S.	115°52′E.	....do.........	Clayey sand; PLEIS	PLEIS-HOLO
Jurien Bay deposit	30°19′S.	115°10′E.	....do.........	Sand; PLEIS	PLEIS
Minninup hind-dune deposit.	33°29′S.	115°34′E.	....do.........	Sand; QUAT	QUAT
Waroona deposit	32°51′S.	115°55′E.	....do.........	Sand, PLEIS	LTERT-PLEIS
Waroona North deposit	32°50′S.	115°55′E.	....do.........	....do.........	....do.........
Yoganup Extended deposit	33°25′S.	115°41′E.	....do.........	Sand, clay; Yoganup Fm; EPLEIS	LTERT(?)-EPLEIS
Yoganup North deposit	33°29′S.	115°44′E.	....do.........	....do.........	....do.........
			BRAZIL		
Mataraca deposit	06°30′S.	35°00′W.	Placer, marine	Sand; CEN	CEN
Pitinga deposit	00°45′S.	60°07′W.	Magmatic; placer continental.	Granite; rhyolite, tuffs; EPROT	EPROT; CEN
Poços de Caldas deposit	21°48′S.	46°33′W.	Magmatic	Nepheline syenite?	—
Vitoria district	18°22°S.	40°–42°W.	Placer, marine	Sand; QUAT	QUAT

records for zirconium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	Reference
		AUSTRALIA—Continued		
Basin	Dune, beach	ILMN, ZRCN, LCXN; QRTZ	Sequence of 10 HM beach and dune-sand units; forms part of Capel Shoreline.	Welch and others (1975); Bell (1988).
....do.........	....do.........	ILMN, ZRCN, RUTL, LCXN, MNZT; QRTZ.	Beach and dune deposit along Munbinea Shoreline; 18-km-long strands (60–90 m asl).	Maunsell and Partners Pty. Ltd. (1987).
....do.........	....do.........	ILMN, ZRCN, RUTL, MNZT, KYNT; QRTZ.	Mineralization occurs in seven beach strandlines (82–128 m asl) and in overlying dunes.	Baxter (1977); Australian Business (1985).
....do.........	Beach, dune	ILMN, ZRCN, RUTL, LCXN, KYNT, MNZT; QRTZ.	Beach and dune deposits at base of Gingin Scarp.	Do.
....do.........	Beach, lagoon?	ILMN, ZRCN, RUTL; QRTZ	Orebody is up to 60 percent HM and 12–30 percent clay. Occurs on Gingin Shoreline for 5 km and is up to 250 m wide, 2–20 m thick.	Baxter (1977).
....do.........	Beach, dune	ILMN, RUTL, ZRCN, GRNT; QRTZ	Five separate HM lenses: three beach, two dune. Occurs along the Munbinea Shoreline.	Baxter (1977); TiO_2 Corporation NL (1985).
....do.........	Dune	ILMN, ZRCN, LCXN; QRTZ	Occurs along Minninup Shoreline in dune sands up to 15 m thick.	Baxter (1977).
....do.........	....do.........	ILMN, ZRCN, LCXN, MNZT; QRTZ	Occurs along Waroona Shoreline in dune sands up to 9 m thick and up to 60 percent HM.	Do.
....do.........	....do.........	ILMN, ZRCN, LCXN, MNZT; QRTZ	....do.........	Do.
....do.........	Beach, dune	ILMN, ZRCN, LCXN, MNZT; QRTZ	Beach and dune deposits in Yoganup Shoreline. Strandlines 43–46 m asl.	Baxter(1982); Bell (1988).
....do.........	....do.........	ILMN, ZRCN, LCXN, MNZT; QRTZ	Beach and dune deposits in Yoganup Shoreline.	Do.
		BRAZIL—Continued		
Basin	Beach, dune	ILMN, ZRCN, RUTL, MNZT, GRNT, TRML; QRTZ.	Series of sand dunes lying parallel with coast, stretching approximately 20 km. Total HM: 5.6 percent.	Harben (1984).
—	—	CSTR, ZRCN, PCLR, CLMB, TNTL, XNTM.	Greisenization of biotite granite produced primary mineralization. Main orebody has a 40-m-thick weathered zone, which, together with associated placer deposits, has been mined for tin.	—
—	—	BDLT, ZRCN, CLDT	Hydrothermal solution leaching and wall rock alteration of alkalic rocks.	Tolbert (1966).
Basin	Coastal beach	ILMN, ZRCN, MNZT, RUTL, MGNT; QRTZ.	Several deposits along 450-km stretch of coast. Two producing deposits at Cumuruxitaba and Guarapari.	Harben (1984); Leonardos (1974).

TABLE 13.—*Selected geologic and location information from ISMI*

Site name	Latitude	Longitude	Deposit type	Host rock	Age of mineralization
			CANADA		
Strange Lake deposit	56°19′N.	64°07′W.	Magmatic, pegmatite	Alkalic granite; MPROT	MPROT
Suncor deposit	57°00′N.	111°29′W.	Placer, marine	Sandstone; McMurray Fm; LCRET	LCRET
Syncrude deposit	57°02′N.	111°37′W.	....do.........	....do.........	....do.........
Thor Lake deposit	62°06′N.	112°35′W.	Magmatic	Syenite; Thor Lake syenite; Aphebian	Aphebian(?)
			CHINA		
Beihai district	21°29′N.	109°06′E.	Placer, marine; placer, continental.	Sand; CEN	CEN
Guangdong Province	21°12′N.	110°33′E.	....do.........	....do.........	....do.........
Sai-Lao district (Quoinghi)	19°15′N.	110°36′E.	Placer, marine	....do.........	....do.........
Wuzhaung district (Wanning).	18°43′N.	110°22′E.	....do.........	....do.........	....do.........
Xun Jiang deposit	23°20′N.	110°50′E.	Placer, continental	....do.........	....do.........
			GREENLAND		
Ilimaussaq deposit	60°54′N.	45°51′W.	Magmatic, igneous, peralkaline.	Sandstone; basalt; Eriksfjord Fm	1,168 Ma?
			INDIA		
Chatrapur deposit	19°18′N.	84°57′E.	Placer, marine	Sand; QUAT	QUAT
Chavara deposit	09°10′N.	76°30′E.	....do.........	....do.........	....do.........

Tectonic setting	Local environment	Principal mineral assemblages	Comments	Reference
		CANADA—Continued		
Cratonic	High-level granite cupola	ELPD, GTTN, KNST, ARMS, GDLN, PCLR, FLRT; QRTZ.	Pegmatite-aplite sill within cogenetic granite.	Miller (1986); Zajac and others (1984).
Alberta Basin	Coastal marine	Zr and Ti minerals	In Athabasca oil sands, HM range from 0.24–2.29 percent.	Kramers and Brown (1976); Trevoy and others (1978).
....do.........	....do.........	Zr and Ti minerals	....do.........	Kramers and Brown (1976); Trevoy and others (1978); Love (1985).
Intracratonic rift	—	Ferro-CLMB, PCLR, BSNS, ALNT, ZRCN, FLRT, HMTT, URNR.	Host rock altered by replacement of HBLD with fine aggregates of HMTT, ALBT, FLRT, and BOTT.	Pinckston and Smith (1988); Trueman and others (1985); Trueman (1986).
		CHINA—Continued		
Basin	Beach plus river sands on coastal plain.	ILMN, ZRCN, MNZT, RUTL; QRTZ	At least half of the 70-km coastline from Beihai to Qinzhou is assumed to contain HM to a depth of 2 m along a width of 2 km. Avg 1.3 percent HM.	U.S. Bureau of Mines (1982).
....do.........	Beach and river sands	ILMN, ZRCN, MNZT, RUTL; QRTZ	Region contains several hundred km of coastline with HM-bearing sands. Five processing plants in region.	Do.
....do.........	Coastal beach	ILMN, ZRCN, MNZT, RUTL, ANTS; QRTZ.	Five parallel strandlines up to 10 km long, 500 m wide, and 5 m thick; 2–3 percent HM.	Do.
....do.........	....do.........	ILMN, ZRCN, MNZT, RUTL, ANTS; QRTZ.	Consists of several strandlines up to 18 km long, 240–800 m wide, and 8–10 m thick.	Do.
....do.........	River plain (100 m asl)	ILMN; minor RUTL, ZRCN, MNZT; QRTZ.	Typically 5 m deep, 5–7 percent HM.	Do.
		GREENLAND—Continued		
Cratonic	High-level alkali basaltic cupola.	EDLT, AFVD/AGRN, MCCL, PRTT, NPLN, RNKT, FLRT, STST, NJKS.	Density stratified cumulate of AGRN, lujavrite, naujaites, and kakortokites cut by late pegmatites and pneumatolytic veins.	Bailey, Bohse, and Demina (1981); Bailey, Larsen, and Sørensen (1981); Larsen and Sørensen (1987).
		INDIA—Continued		
Basin	Coastal beach	ILMN, SLMN, RUTL, MNZT, ZRCN; QRTZ.	Aeolian sand dunes in a belt 1,500 m wide with two main transverse ridges. Maximum 17 m asl. Approximately 20 percent HM.	U.S. Bureau of Mines (1982); Clarke (1983).
....do.........	....do.........	ILMN, RUTL, ZRCN, LCXN, MNZT; QRTZ.	Deposit is on a barrier beach. HM content avg 80 percent in shore sands, 45 percent in dunes. HM composed of 6 percent ZRCN.	Adams (1984).

TABLE 13.—*Selected geologic and location information from ISMI*

Site name	Latitude	Longitude	Deposit type	Host rock	Age of mineralization
			INDIA—Continued		
Manavalakurichi deposit	08°12′N.	77°20′E.	Placer, marine	Sand; QUAT	QUAT
			MADAGASCAR		
Taolanaro district	25°S.	47°E.	Placer, marine	Sand; CEN	CEN
			MOZAMBIQUE		
Pebane district	17°S.	38°E.	Placer, marine	Sand; QUAT	QUAT
			NEW ZEALAND		
Barrytown deposit	42°14′S.	171° 19′E.	Placer, marine	Sand; Nine Mile Fm; QUAT	QUAT
Westport deposit	41°47′S.	171°33′E.	....do.........	....do.........	....do.........
			SOUTH AFRICA		
Bothaville deposit	27°11′S.	26° 30′E.	Placer, marine	Sand; Middle Ecca Fm; CARB-PERM	CARB-PERM
Cape Morgan deposit	32°42′S.	28°22′E.	....do.........	Sand; HOLO	HOLO
Ciskei Coast deposit	33°14′S.	27°33′E.	....do.........	....do.........	....do.........
North Natal Coast deposit	28°42′S.	32°10′E.	....do.........	Sand; QUAT	QUAT
Phalaborwa deposit	23°59′S.	31°07′E.	Magmatic, carbonatite/ alkalic.	Phoscorite/pyroxenite; ARCH	ARCH
Transkei Coast deposit	32°35′S.	28°31′E.	Placer, marine	Sand; PLEIS	PLEIS
Umgababa deposit	30°08′S.	30°51′E.	....do.........	Sand; HOLO	HOLO
West Cape Coast deposit	30°36′S.	17°36′E.	....do.........	....do.........	....do.........

records for zirconium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	Reference
		INDIA—Continued		
Basin	Coastal beach	ILMN, RUTL, ZRCN, MNZT, GRNT; QRTZ.	Deposit contains buried seams of rich, black sand. Annual replenishment of about 50,000 t of sand from offshore deposits by wave action.	Clarke (1983).
		MADAGASCAR—Continued		
Basin	Coastal	ILMN, ZRCN; QRTZ	No details are available.	Mining Magazine (1986).
		MOZAMBIQUE—Continued		
Basin	Coastal beach	ILMN, ZRCN, MNZT, RUTL; QRTZ	Beach and dune-sand deposits along the coast around Pebane. Grades of up to 85 percent HM are present.	Adams (1984); U.N. Economic Commission for Africa (1981).
		NEW ZEALAND—Continued		
Basin	Coastal beach	ILMN, GRNT, ZRCN, MGNT, RUTL, MNZT; QRTZ; FLDP.	Deposit extends 1 km inland from present-day shoreline. It is 5.2 m thick, contains band of pebbles and gravel. Additional resources in PLEIS strandlines further inland.	McPherson (1978); Ward (1972).
....do.........	....do.........	....do.........	....do.........	Do.
		SOUTH AFRICA—Continued		
Basin	Coastal beach	ILMN,HMTT, RUTL, LCXN, MGNT, ZRCN; QRTZ, GRNT.	Ore is in consolidated-laminated sandstone. Deposits occur in a zone 16 km long and 12 m wide. Largest deposit is 4 km long and 900 m wide.	Hammerbeck (1976).
....do.........	Coastal sand dunes	ILMN, RUTL, MGNT, ZRCN; QRTZ	Total strike length of HM sands is approximately 5 km. Ore is in nonlayered aeolian dunes.	Do.
....do.........	....do.........	ILMN, RUTL, MGNT, ZRCN, LCXN; QRTZ, CLAY.	Consists of nonlayered aeolian dunes. Strike length approximately 6 km. Very high HM content.	J.P. Nickolas Company reports (proprietary).
....do.........	Coastal beach and dunes	ILMN, LCXN, RUTL, ZRCN, GRNT	Ore is in nonlayered HOLO aeolian dunes and in well-layered PLEIS beach sand (1 m of cover). Deposits occur along length of 110 km.	Hammerbeck (1976).
Volcanic plug	Granite, gneisses	APTT, CLCP, CLCC, BRNT, VLRT, CBNT, MGNT, BDLT, VMCL.	Deposit is 8 km long and 3.2 km wide, with 14 distinct rock types.	Kawata and others (1986); Keyser (1976).
Basin	Coastal sand dunes	ILMN, RUTL, ZRCN, MGNT; QRTZ	Deposit is in layered dunes behind the beach and extends along 17 km.	Hammerbeck (1976).
....do.........	....do.........	ILMN, RUTL, ZRCN, MGNT; QRTZ	Nonlayered aeolian dunes along a length of 6 km.	Langton and Jackson (1961); Hammerbeck (1976).
....do.........	....do.........	ILMN, RUTL, ZRCN, MGNT; QRTZ	Nonlayered aeolian dunes underlain by consolidated sand in 20-km-wide coastal strip.	Hammerbeck (1976).

TABLE 13.—*Selected geologic and location information from ISMI*

Site name	Latitude	Longitude	Deposit type	Host rock	Age of mineralization
			SOVIET UNION		
Dnepropetrovsk district	48°40′N.	34°22′E.	Placer, marine	Sand; Samotkan placer; TERT	TERT
Kovdor Complex	67°34′N.	30°27′E.	Magmatic, carbonatite/ alkalic.	Ijolites, pyroxenites; MDEV(?) Kovdor Complex; MDEV(?).	MDEV(?)
Lovozero deposit	67°46′N.	35°05′E.	Magmatic, peralkaline hosted.	Gneiss, granite gneiss, M-LDEV Migmatite; LARCH.	MDEV-LDEV
			SRI LANKA		
Pulmoddai deposit	08°57′N.	80°57′E.	Placer, marine	Sand; QUAT	QUAT
			UNITED STATES		
Brunswick deposit	31°19′N.	81°28′W.	Placer, marine	Sand; PLEIS	PLEIS
Cumberland Island deposit	30°51′N.	81°26′W.	....do.........	Sand; Silver Bluff shoreline complex; PLEIS	....do.........
Green Cove Springs deposit	29°50′N.	81°42′W.	....do.........	Sand; PLEIS	....do.........
Kerr-McGee deposit	36°07′N.	88°11′W.	....do.........	Sand; McNairy Fm; LCRET	LCRET
Lakehurst deposit	40°04′N.	74°20′W.	Placer, marine; placer, continental.	Sand; Cohansey Sand; MIO-PLIO	MIO-PLIO
Natchez Trace deposit	35°50′N.	88°12′W.	....do.........	Sand; McNairy Fm; LCRET	LCRET
Oak Grove deposit	36°23′N.	88°10′W.	....do.........	....do.........	....do.........
Soledad Canyon district	34°23′N.	118°20′W.	Placer, continental	Alluvials; QUAT(?)	QUAT(?)
Trail Ridge (Starke and Highland) deposit.	30°02′N.	82°02′W.	Placer, marine	Aeolian sand; PLEIS	PLEIS

records for zirconium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	Reference
		SOVIET UNION—Continued		
Basin	Coastal beach	ILMN, RUTL, LCXN, ANTS, ZRCN; QRTZ.	Deposit attains thickness of tens of m, a width up to several km, and length of tens of km. Occurs as layers or lenses.	U.S. Bureau of Mines (1982); Coope (1982).
Baltic Platform	Alkaline magmatic complex.	MGNT, APTT, BDLT, FRSR, carbonatite minerals, PYRT.	Orebody 1.3 km long, 200–800 m wide, striking north.	Gorbunov (1981); Dalheimer and others (1988).
Craton	—	MCCL, AGRN, EDLT, AFVD, NPLN	Stratified lopolith of miaskitic nepheline syenites, urites, foyaite crosscuts, overlain by a sill-like intrusion of eudialyte, lujavrites.	Kogarko (1987); Gerasimovsky and others (1974).
		SRI LANKA—Continued		
Basin	Coastal beach	ILMN, RUTL, ZRCN, MNZT; QRTZ	Deposit is 7.5 km long and 60 m wide (may reach a width of 250 m). Avg thickness is 6 m with overburden. Further resources are in backshore areas and an offshore strip hundreds of m wide, which replenishes excavated sand.	Adams (1984); Clark (1983).
		UNITED STATES—Continued		
Basin	Shoreline	ILMN, minor RUTL, LCXN, ZRCN, MNZT; QRTZ.	—	Fantel and others (1986).
....do.........	....do.........	ILMN, minor RUTL, LCXN, ZRCN, MNZT; QRTZ.	Avg grade 1.7 percent HM containing 13 percent ZRCN.	E.R. Force, (oral commun., USGS, November 1984).
....do.........	....do.........	ILMN, RUTL, LCXN, ZRCN, MNZT; QRTZ.	Consists of several strandlines 16 m thick; grade ranges from 2–5 percent HM with small lenses up to 40 percent HM.	Pirkle and others (1974).
....do.........	....do.........	ILMN, RUTL, ZRCN, MNZT; QRTZ	Mineralization is in the extensive McNairy sand. The unit contains very fine sands with 15–25 percent clays.	Fantel and others (1986); Wilcox (1971).
....do.........	Deltaic	ILMN, ZRCN, LCXN, RUTL, KYNT; QRTZ.	Deposit occurs in a 7-m-thick, medium-grained quartz sandstone. Original grade was 4–5 percent HM.	Puffer and Cousminer (1982).
....do.........	Shoreline	ILMN, RUTL, ZRCN, MNZT, KYNT; QRTZ.	Similar geology to Kerr-McGee deposit.	Hershey (1968).
....do.........	....do.........	ILMN, RUTL, LCXN, ZRCN, MNZT, KYNT, STRL, TRML; QRTZ.	....do.........	Wilcox (1971).
—	—	ILMN, MGNT, APTT, ZRCN	Alluvial deposits derived from a gabbro-anorthosite complex.	—
Basin	Shoreline, aeolian dune	ILMN, LCXN, RUTL, ZRCN, KYNT, SLMN, STRL; QRTZ.	Well-sorted crossbedded, unconsolidated sand impregnated with humate, 8–20 m thick. Avg grade 2.5–3 percent HM.	Force and Garnar (1985); Pirkle and Yoho (1970).

TABLE 14.—*Selected production and mineral-resource information*

Abbreviations used throughout this table include
—, no information available
t, metric tons
conc, concentrate

Abbreviations for *mining method* are S, surface; N, not producing.

All percentages refer to zircon unless otherwise indicated.

Annual production includes some or all of the following items (separated by semicolons): annual production in thousand metric tons; grade of reported material in percent zircon; year of production (or range of years used to estimate average annual production); and degree of accuracy (accurate (Acc) or estimate (Est)).

Cumulative production includes some or all of the following items (separated by semicolons): cumulative production in thousand metric tons; grade of reported material in percent zircon; years of reported cumulative production; and degree of accuracy (accurate (Acc) or estimate (Est)).

Resources includes, for various resource categories, some or all of the following items (separated by semicolons): resource in thousand metric tons; U.N. resource classification (see fig. 1); grade of reported material in percent zircon (unless otherwise indicated); and year of estimate (R indicates year of reference in which estimate appears).

Site name	Year of discovery	Mining method	Year of first production	Commodities
AUSTRALIA				
EAST COAST				
Agnes Water deposit	1956	N	None	ILMN, ZRCN, RUTL
Bayfield deposit	1956	N	None	ZRCN, ILMN, RUTL
Bridge Hill Ridge deposit	Mid-1950's	S	1974	RUTL, ZRCN, ILMN
Fraser Island	1956	S	1971	RUTL, ZRCN
Moreton Island	1950's	N	1957	RUTL, ILMN, ZRCN
North Stradbroke Island	1947	S	1950	RUTL, ZRCN, ILMN, MNZT.
Stockton deposit	1962	S	1984	ZRCN, RUTL
Tomago deposit	1965	S	1972	RUTL, ZRCN, ILMN
Viney Creek deposit	1968	S	1986	RUTL, ZRCN, ILMN
WIM–150 deposit	1982	N	None	ILMN, RUTL, ZRCN, MNZT, XNTM.
WEST COAST				
Brockman deposit	1973	N	None	Nb, Ta, Y, Zr, REO, Hf, Ga.
Capel (AMC) deposit	1954	S	1956	ILMN, ZRCN, LCXN, MNZT.
Cooljarloo deposit	1971	N	None	ILMN, LCXN, ZRCN, RUTL.
Eneabba (Allied) deposit	1968	S	1974	ILMN, RUTL, ZRCN
Eneabba (AMC) deposit	1968	S	1974	ILMN, RUTL, ZRCN
Gingin deposit	1971	N	None	ILMN, RUTL, ZRCN
Jurien Bay deposit	1971	S	1975	RUTL, ILMN, ZRCN
Minninup hind-dune deposit	1948	S	1986	ILMN, ZRCN

from ISMI records for zirconium deposits and districts

Abbreviations for mineral names (after Longe and others, 1978, p. 63–68):

Apatite	APTT	Kyanite	KYNT
Baddeleyite	BDLT	Leucoxene	LCXN
Caldasite	CLDT	Monazite	MNZT
Cassiterite	CSTR	Rare earth oxides	REO
Eudialyte	EDLT	Rutile	RUTL
Garnet	GRNT	Sillimanite	SLMN
Gold	GOLD	Vermiculite	VMCL
Heavy minerals	HM	Xenotime	XNTM
Ilmenite	ILMN	Zircon	ZRCN

Annual production (in 1,000 t)	Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
		AUSTRALIA—Continued	
None	None	ZRCN: 420; R1E; 1978	Undeveloped property.
None	None	Ore: 2,400; R1M; 1986	Undeveloped property; undergoing feasibility study.
None	ZRCN: 142.897; 1974–83; Acc.	ZRCN: 211; R1E; 1973	Most of these resources are unavailable due to environmental restrictions. Mining ceased in 1983; future mining appears unlikely.
None	ZRCN: 32.783; 1971–75; Acc.	ZRCN: 832; R1E; 1976	Operation ceased due to government environmental restrictions.
None	ZRCN: 3.312; 1957–58; Acc.	ZRCN: 676.333; R1E; 1977 ZRCN: 208.048; R2E; 1977	Do.
ZRCN: 90.7; 1985–86; Acc.	ZRCN: 1,160; 1966–86; Acc.	ZRCN: 1,317; R1E; 1986	Consolidated Rutile Ltd. is currently developing new leases. Future looks very promising.
ZRCN: 8.583; 1984; Acc.	ZRCN: 12.201; 1984–85; Acc.	ZRCN: 17.3; R1E; 1977	Projected mine life of 6–8 years.
ZRCN: 39.803; 1986; Acc.	ZRCN: 756.776; 1967–86; Acc.	ZRCN: 260; R1E; 1983R	Further mine life of 8 years including reworking of tailings.
Included with Stockton deposit.	Included with Stockton deposit.	ZRCN: 170; R1E; 1985	Mine life of 8 years; commenced in July 1986.
None	None	ZRCN: 5,100.0; R1M; 1988	Fine-grain size of HM affects the recovery rate and causes further processing problems. May be in operation by 1992.
None	None	Ore: 9,290; R1M; 1.04 percent ZrO_2; 1987.	Project is a very complex one; final feasibility report due in March 1998.
ZRCN: 10,047; 1986; Acc.	ZRCN: 473.7; 1956–86; Acc.	ZRCN: 110.9; R1E; 1987; Est	Mine life of resource is only about 10 years.
None	None	ZRCN: 1,823.6; R1E; 1988; Est HM: 14,600; R1E; 1988; Acc	Production planned to commence in 1990.
ZRCN: 118.953; 1986; Acc.	ZRCN: 1,323.9; 1975–86; Acc.	HM: 10,822; R1E; 1984 ZRCN: 1.905; R1E; 1984	Mining of deposit is linked with Eneabba Associated Minerals Consolidated Ltd.
ZRCN: 120.815; 1986; Acc.	ZRCN: 878.26; 1974–86; Acc.	ZRCN: 4,132; R1E; 1987	Resources include other areas owned at Capel and east coast (as of 1987), and the U.S. 1987 resources figure includes the Eneabba (Allied) deposit.
None	None	ZRCN: 130; R1S; 1976.	Development is being deferred until a definite market is established.
None	ZRCN: 6.607; 1975–77; Acc.	ZRCN: 252.8; R1M; 1987R ZRCN: 10.237; R2S; 1987R	Inactive since 1977.
ZRCN: 8.878; 1986; Acc.	ZRCN: 15.342; 1985–86; Acc.	Company proprietary	—

TABLE 14.—*Selected production and mineral-resource information from*

Site name	Year of discovery	Mining method	Year of first production	Commodities
AUSTRALIA—Continued				
WEST COAST—Continued				
Waroona deposit	1970	N	None	ILMN, ZRCN, LCXN, MNZT.
Waroona North deposit	—	S	1985	ILMN, ZRCN, LCXN
Yoganup Extended deposit	1954	S	1972	ILMN, LCXN, ZRCN, MNZT.
Yoganup North deposit	1954	S	1987	ILMN, LCXN, ZRCN, MNZT.
BRAZIL				
Mataraca deposit	1970?	S	1984	ILMN, ZRCN, RUTL
Pitinga deposit	1980	S	1982	CSTR, ZRCN
Poços de Caldas deposit	—	S	1935	BDLT, ZRCN (CLDT)
Vitoria district	—	S	Pre-1925	ILMN, RUTL, ZRCN, MNZT.
CANADA				
Strange Lake deposit	1979	N	None	ZRCN, Y, Be, Nb, REO
Suncor deposit	1778	S	1967	Crude oil, S, V, Ni, LCXN, ILMN, RUTL, ZRCN.
Syncrude deposit	1778	S	1978	Crude oil, S, V, Ni, LCXN, ILMN, RUTL, ZRCN.
Thor Lake deposit	1979	N	None	ZRCN, Ta, Ce, Sm, La
CHINA				
Beihai district	—	S	1966	ILMN, RUTL, ZRCN, MNZT.
Guangdong Province	—	S	About 1960	ILMN, RUTL, ZRCN, MNZT.
Sai-Lao district (Quoinghi)	Pre-1940	S	1958	ILMN, RUTL, ZRCN, MNZT.
Wuzhaung district (Wanning)	Pre-1940	S	1965	ILMN, RUTL, ZRCN, MNZT.
Xun Jiang deposit	1975	N	None	ILMN, RUTL, ZRCN, MNZT.
GREENLAND				
Ilimaussaq deposit	1970's	N	None	Zr, Nb, REO

ISMI records for zirconium deposits and districts—Continued

Annual production (in 1,000 t)	Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
		AUSTRALIA—Continued	
None	None	ZRCN: 36.972; R1E; 1981	Deposit is essentially an ILMN deposit with a potential mine life of about 5 years.
Included with Minninup hind-dune deposit.	Included with Minninup hind-dune deposit.	Company proprietary	—
ZRCN: 32.138; 1986; Acc.	ZRCN: 538.9; 1959–86; Est.	....do.........	Company has substantial resources lasting at least to the year 2000.
Included with Yoganup Extended deposit.	Included with Yoganup Extended deposit.	....do.........	Do.
		BRAZIL—Continued	
Included with Vitoria deposit.	Included with Vitoria deposit.	ZRCN: 535.5; R1E; 67.0 percent; 1984 ZRCN: 204.8; R1S; 1984	ZRCN production is used locally.
ZRCN: None	ZRCN: None	ZRCN: 2,000; R1E; 1988	Brazil's largest tin mine; ZRCN production planned for early 1990's.
—	ZRCN: 58.96; 1935–52.	ZRCN: 33.2; R1E; 58.73 percent ZrO_2; 1983. ZRCN: 46.2; R2E; 1983	Ore contains CLDT.
ZRCN: 9; 1983–85; Est.	ZRCN: 164.102; 1947–85; Acc.	ZRCN: 262; R1E; 64 percent; 1983	Production figure includes all Brazilian CLDT, BDLT, and ZRCN production.
		CANADA—Continued	
None	None	Ore: 52,000; R1S and R2S; 3.25 percent ZrO_2; 1982.	Development contingent upon adequate world market for yttrium and final development of processing technology.
None	None	Bitumen: 84,000; R1E; 1 percent HM; 1984.	Zr minerals are recoverable from scroll tailings that remain after the recovery of bitumen from the oil sand. ZRCN content is approximately 35 percent.
None	None	Bitumen: 207,000; R1E; 1 percent HM; 1984.	Some 41,000 t of Zr minerals could be recovered from 700,000 t of tailings.
None	None	Ore: 63,500; R1M; 4.73 percent ZrO_2; 1987.	ZRCN has high Fe content, contains up to 3 weight percent Y_2O_3 and 2 weight percent HfO_2.
		CHINA—Continued	
ZRCN: 15; 62 percent; 1981–85; Est.	ZRCN: 119; 1977–85; Est.	ZRCN: 28; R2E; 1987	Political resistance to mechanized mining could arise from farmers who mine the sands by hand. Resources are approximately 50 percent in beach, 50 percent in river sands.
Included with Beihai district.	Included with Beihai district.	ZRCN: 1,070; R1E; 1982R	Mine life is greater than 30 years. Sand is hand mined by farmers.
....do.........	....do.........	ZRCN: 67; R1E; 1982R	Sand is hand mined by farmers.
....do.........	....do.........	ZRCN: 291.106; R1E; 1982R	In the past, mechanized mining and concentration has been used to supply up to one-third of plant feed.
None	None	—	Government is interested in developing deposit. Mechanized mining is likely.
		GREENLAND—Continued	
None	None	Ore: 86,000; R2S; 1981 Ore: 5,000; R2S; 1987 Ore: 3,000; R1M; 1987	Deposit is rich in niobium and rare earth minerals.

TABLE 14.—*Selected production and mineral-resource information from*

Site name	Year of discovery	Mining method	Year of first production	Commodities
		INDIA		
Chatrapur deposit	1958	S	1984?	ILMN, RUTL, SLMN, MNZT, ZRCN.
Chavara deposit	—	S	1932	ILMN, RUTL, ZRCN, MNZT, SLMN.
Manavalakurichi deposit	—	S	1911	ILMN, RUTL, ZRCN, MNZT, GRNT.
		MADAGASCAR		
Taolanaro deposit	—	N	1958	ILMN, ZRCN
		MOZAMBIQUE		
Pebane district	—	S	1958	ILMN, RUTL, ZRCN, MNZT.
		NEW ZEALAND		
Barrytown deposit	1860's	N	None	GOLD, ILMN, ZRCN, MNZT.
Westport deposit	1860's	N	None	GOLD, ILMN, ZRCN, MNZT.
		SOUTH AFRICA		
Bothaville deposit	1955	N	None	ILMN, RUTL, ZRCN
Cape Morgan deposit	1954	S	1969	ILMN, RUTL, ZRCN
Ciskei Coast deposit	—	N	None	ILMN, RUTL, ZRCN
North Natal Coast deposit	1968	S	1977	ILMN, RUTL, ZRCN, Ti slag, low Mn iron.
Phalaborwa deposit	1906	S	1955	APTT, BDLT, VMCL, Cu, U.
Transkei Coast deposit	—	N	None	ILMN, RUTL, ZRCN
Umgababa deposit	1948	S	1955	ILMN, RUTL, ZRCN
West Cape Coast deposit	1970	N	None	ILMN, RUTL, ZRCN

ISMI records for zirconium deposits and districts—Continued

Annual production (in 1,000 t)	Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
		INDIA—Continued	
—	—	Ore: 240,000; R1E; 0.4 percent ZRCN; 1982R. ZRCN: 960; R1E; 1982R Ore: 350,000; R2E; 0.4 percent ZRCN; 1982R. ZRCN: 1,400; R2E; 1982R	Plant was expected to be in operation by mid-1988.
ZRCN: 7,700; 1985–86; Est.	ZRCN: 139.511; 1932–86; Est.	ZRCN: 2,600; R1E; 1985R	Current production is from two plants; Indian Rare Earths Ltd. (major) and Kerala Minerals and Metals Ltd. (minor).
ZRCN: 6; 1982 (maximum capacity).	ZRCN: 100; 1967–86; Est.	—	Cumulative production from Indian Rare Earths Ltd. only. Deposit is much smaller than Chavara.
		MADAGASCAR—Continued	
None	ZRCN: 3.437; 1958–67; Acc.	ZRCN: 3,000; R1E; 1988	Joint venture between the government and Canada's QIT-Fer et Titane. Feasibility study is still underway.
		MOZAMBIQUE—Continued	
None	None	ZRCN: 218.240; R1E; 1988	Development is proposed by the government, but no formal plans have been announced.
		NEW ZEALAND—Continued	
None	None	ZRCN: 180; R2E; Est	A pilot plant to process the ILMN directly into TiO_2 pigment was planned for 1987–88. Further development depends on it.
None	None	ZRCN: 256; R2E; 1978R ZRCN: 1,000; R2S; 1978R	R2E deposits are in Holocene sands on or near present shoreline. R2S deposits are in Pleistocene sands, inland.
		SOUTH AFRICA—Continued	
None	None	Ore: 34,000; R1S; 2.6 percent ZRCN ZRCN: 884; R1S; 1988	Deposit is in a remote area.
None	ZRCN: 126; 66.20 percent; 1969; Est.	Ore: 64,000; R1S; 0.25 percent ZRCN; 1984. ZRCN: 160; R1S; 1984	1969 was the only year of production.
None	None	Ore: 64,000; R1S; 0.5 percent ZRCN; 1984. ZRCN: 320; R1S; 1984	Grade is too low for exploitation.
ZRCN: 160; 1986; Est.	ZRCN: 1,300; 1977–86; Est.	Ore: 1,694,000; R1E; 0.6 percent ZRCN; 1984. Ore: 455; R1M; 0.6 percent ZRCN; 1984	South Africa's only mineral-sands producing area.
BDLT: 10.129; 1987; Acc.	BDLT: 82.289; 1972–87; Acc.	BDLT: 325; R1E; 1970 BDLT: 540; R1E; 1976	BDLT is a byproduct of copper and phosphate mining by two companies, Foskor and Palabora Mining Company.
None	None	Ore: 249,000; R1E; 0.6 percent ZRCN; 1988. Ore: 149,000; R1S; 0.39 percent ZRCN; 1984.	Remote area; economic viability depends on possible offshore loader.
None	ZRCN: 47; 66.40 percent; 1955–63; Est.	Ore: 44,000; R1S; 1.3 percent ZRCN; 1984.	Operations ceased in 1963 due to technical problems and pollution of local resorts. No plans for redevelopment.
None	None	Ore: 100,000; R1S; 1.5 percent ZRCN; 1984.	Remote area, but some prospects for mining.

TABLE 14.—*Selected production and mineral-resource information from*

Site name	Year of discovery	Mining method	Year of first production	Commodities
		SOVIET UNION		
Dnepropetrovsk district	Pre-1957	S	1960	ILMN, RUTL, ZRCN
Kovdor Complex	1933	S	1976	BDLT
Lovozero deposit	—	N	None	EDLT
		SRI LANKA		
Pulmoddai deposit	1920	S	1961	ILMN, RUTL, ZRCN, MNZT.
		UNITED STATES		
Brunswick deposit	1955?	N	None	ILMN, RUTL, LCXN, ZRCN.
Cumberland Island deposit	—	N	None	ILMN, RUTL, LCXN, ZRCN.
Green Cove Springs deposit	1969	S	1972	ILMN, RUTL, LCXN, ZRCN, MNZT.
Kerr-McGee deposit	1956	N	None	ILMN, RUTL, ZRCN, MNZT.
Lakehurst deposit	1957	S	1962	ILMN, LCXN, RUTL, ZRCN.
Natchez Trace deposit	1956	N	None	ILMN, RUTL, ZRCN, MNZT, KYNT.
Oak Grove deposit	1956	N	None	ILMN, RUTL, ZRCN, MNZT, KYNT.
Soledad Canyon district	1944	S	1985	ILMN, MGNT, APTT, ZRCN.
Trail Ridge (Starke and Highland) deposit	1946	S	1949	ILMN, LCXN, RUTL, ZRCN, KYNT.

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ISMI records for zirconium deposits and districts—Continued

Annual production (in 1,000 t)	Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
		SOVIET UNION—Continued	
—	—	—	Ukrainian placer deposits provide the majority of Soviet ZRCN production.
BDLT: 17	—	None	BDLT is a byproduct of magnetite and apatite mining. Only resources of ore containing Fe and P are reported.
None	None	—	Very little information is available on this deposit.
		SRI LANKA—Continued	
ZRCN: 5.335; 1983; Acc.	ZRCN: 22:5; 1971–83; Acc.	Ore: 4,000; R1E; 8–10 percent ZRCN; 1984R. ZRCN: 400; R1E; 1987; Est	An additional 1.3 million metric tons is estimated offshore.
		UNITED STATES—Continued	
None	None	Company proprietary	Resources are in the R1M category.
None	None	ZRCN: 100; R1M; 1986	Deposit is in a national park, so future development appears unlikely.
Company proprietary (maximum capacity: ZRCN: 30).	Company proprietary.	ZRCN: 1,400; R1E; 0.35 percent; 1984; Est. ZRCN: 1,750; R2E; 0.35 percent; 1984; Est.	Resources include all Florida deposits. Production is expected to continue to 2011.
None	None	Company proprietary	Excellent prospects if fine-grain-size problem is overcome.
None	ZRCN: 64; Est	ZRCN: 15; R1M; 0.18 percent of ore; 1986.	Only lower grade material is left. No active exploration or plans for development.
None	None	ZRCN: 1,010; R1M; 1968	Deposit is in a State park, so the outlook is not good.
None	None	Company proprietary	Good prospects for development if fine-grain-size problem is overcome.
Company proprietary.	Company proprietary.	ZRCN: 4,500; R1E; 1986	ZRCN is a byproduct of a sand-and-gravel operation.
....do.........	....do.........	Included with Green Cove Springs deposit	Du Pont has two plants operating on the deposit. Production from Du Pont leases are expected to continue to 2010.

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