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U.S. GEOLOGICAL SURVEY CIRCULAR 930–G

International Strategic Minerals Inventory Summary Report—Titanium

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

Major geologic age units

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	

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By Roy R. Towner, Jonathan M. Gray, and Lyn M. Porter

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FOREWORD

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

The report was prepared by Roy R. Towner, Jonathan M. Gray, and Lyn M. Porter of the Australian Bureau of Mineral Resources, Geology and Geophysics. Titanium inventory information was compiled by Eric R. Force, U.S. Geological Survey (USGS); Ian Goldberg, South African Department of Mineral and Energy Affairs (MEA), Minerals Bureau; David M. Sutphin, USGS; Sebastiaan J. Van Graan, MEA, Minerals Bureau; Jan Zwartendyk, David E. C. King, and Andrew G. Sozanski, Canadian Department of Energy, Mines and Resources (EMR), Mineral Policy Sector (MPS); and Gordon A. Gross, EMR, Geological Survey of Canada. Additional contributions to the report were made by Langtry E. Lynd and Aldo F. Barsotti, U.S. Bureau of Mines, John H. DeYoung, Jr., USGS; and Antony B. T. Werner and Jan Zwartendyk, EMR, MPS.

Director

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INTERNATIONAL STRATEGIC MINERALS INVENTORY SUMMARY REPORT

TITANIUM

By Roy R. Towner, Jonathan M. Gray, *and* Lyn M. Porter[1]

ABSTRACT

Ilmenite and rutile are currently the most important titanium-bearing minerals, although anatase may be important in the future. Both ilmenite and rutile occur in hard-rock and placer deposits, but at present all rutile production and about half of the ilmenite production are from placer deposits. Anatase occurs in laterite deposits in Brazil, which at present are largely undeveloped.

World ilmenite resources in identified deposits that are economically exploitable (R1E) are sufficient for about 150 years at current production rates, and about two-thirds of these resources are in China, the Soviet Union, and Norway. World rutile R1E resources would last about 80 years at current production rates, and some 54 percent of these resources are in Australia, the United States, and Italy. Combined R1E resources of anatase (which are all in Brazil) and rutile would last 300 years at current rutile production rates.

Over 95 percent of the world's mine production of titanium-bearing minerals is used to manufacture titanium dioxide pigment for paint and other products. Most of the remaining 4 to 5 percent of production, which is largely rutile, is used for making titanium metal. Australia and Canada are the largest ilmenite producers, together supplying about half the world total; South Africa, Norway, and the Soviet Union together account for another third. Australia accounts for half the total world rutile production, with Sierra Leone and South Africa together accounting for another third. Australia and Norway are the largest exporters of titanium minerals.

Unless major new deposits are discovered and developed in the traditional producing countries, the pattern of world production of both ilmenite and rutile could change substantially by 2020.

[1]Authors are with the Bureau of Mineral Resources, Geology and Geophysics, Australian Department of Resources 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 has 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. It was 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 titanium in a format designed to be of benefit to 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 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 development are not specifically addressed in this report. The report addresses the primary stages in the supply process for titanium and does not include considerations of titanium 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 to its defense industry. Usually, the term implies a nation's perception of vulnerability to supply disruptions and of a need to safeguard its industries from the repercussions of a loss of supplies.

Because a mineral that is strategic to one country may not be strategic to another, no one 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 and cobalt, have now been published. Additional studies on titanium (this report), graphite, tungsten, vanadium, tin, and zirconium have been subsequently undertaken.

The data in the ISMI titanium inventory were collected from January 1984 to February 1986. The report was submitted for review and publication in July 1986. 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 and 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.

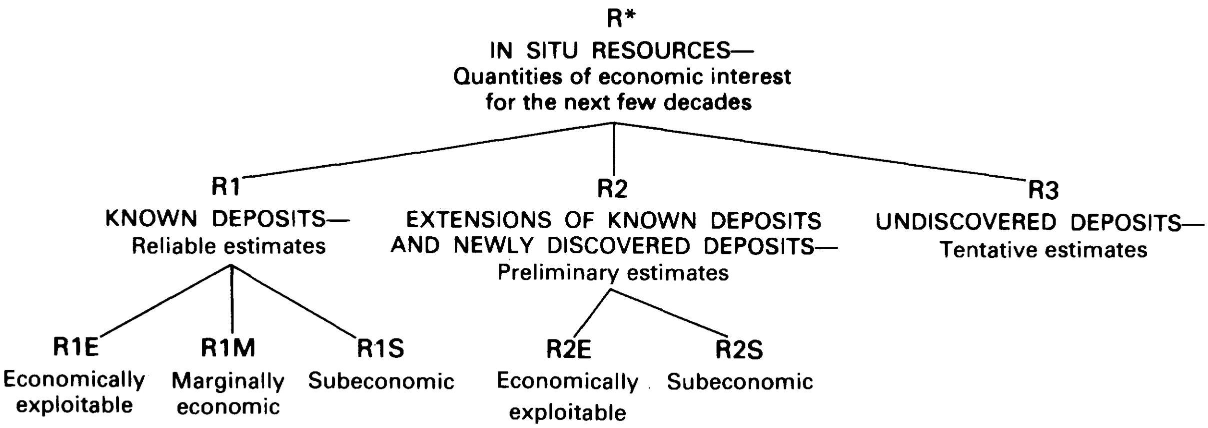
No geologic definition of a deposit (or district) is used for compiling records for this report. Deposits (or districts) are selected for the inventory on the basis of their present or expected future contribution to world supply. Records for all deposits compiled by ISMI participants meet this general "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 Zhanjiang (China) and Perak-Selangor (Malaysia), refer to districts which 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 titanium 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 U.N. resource classification used here. This report focuses on category R1, which covers 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.

The term "ore" in tables 9 and 10 (Part II) refers to mineralized rock or sediment which contains an economic quantity of titanium-bearing minerals whether in the form of rutile, ilmenite, leucoxene, or titanomagnetite or in any combination thereof.

Not all companies or countries report resource data in the same way. In this report, all



*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).

resource data are quoted as being in place. Mining recovery from an ore body depends on individual conditions and may vary considerably. For placer deposits, in excess of 90 percent of the ore is generally recovered; for open-cut primary deposits, mining recovery is generally in the order of 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 metallurgical recovery rates of hard-rock ore depend very much on grain size.

The World Bank economic classification of countries (World Bank, 1985, p. 174–175), which is based primarily on GNP per capita, has been 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

Titanium was named after the Titans, the first sons of the Earth in Greek mythology, to indicate the strength of the element. All igneous rocks contain at least a trace of titanium, and some 60 minerals have it in their listed chemical composition. Approximately 0.62 percent of the Earth's crust is titanium (1.05 x 10^{14} metric tons), making it the ninth most abundant element.

Despite the widespread distribution of titanium in the crust, however, there are relatively few economic deposits of titanium minerals. The economic viability of deposits is determined not only by grade and available tonnage but also by the constituent mineralogy and deposit type. Titanium never occurs in nature in the free state; it is generally in chemical combination with oxygen as titanium dioxide (TiO_2). The main titanium-bearing minerals are listed in table 1.

Rutile, ilmenite, leucoxene, and titanomagnetite are the only titanium-bearing minerals currently being mined. Leucoxene is actually a fine-grained alteration product of other titanium minerals, usually ilmenite. Titanomagnetite is of lesser economic significance. To be of commercial interest, titanomagnetite must have a titanium grade approaching 20 percent, or it must contain another important element such as vanadium.

Anatase has great potential as a future source of titanium. Concentrates have been produced successfully at a pilot plant in Tapira, Brazil. As a result, the very large resources of this mineral in Brazil may soon be exploited. Perovskite and sphene are also important as a potential source of titanium. Large deposits occur in the United States and the Soviet Union, but as yet there has been no commercial exploitation of these minerals. Brookite does not occur in quantities significant enough to be seriously considered for exploitation.

Mining of titanium deposits is generally by open-pit methods, although in some deposits, such as the Otanmaki mine in Finland, underground methods are used. Secondary "mineral sand"

Table 1.—*Principal titanium-bearing minerals*

Mineral	Ideal formula	Usual TiO_2 content (percent)
Rutile	TiO_2	92-98
Anatase	TiO_2	90-95
Brookite	TiO_2	90-100
Ilmenite	$FeTiO_3$	35-60
Leucoxene	Fe_2TiO_5	60-90
Perovskite	$CaTiO_3$	40-60
Sphene	$CaTiSiO_5$	30-42
Titanomagnetite	$TiFe_2O_4$	2-20

deposits are commonly exploited by suction or bucket-line methods of dredging. Primary "hard-rock" deposits and some of the more indurated secondary deposits require blasting, front-end loaders, shovels, and other heavy earth-moving equipment. The mined ore is processed by a combination of gravity, magnetic, electrostatic, and chemical separation methods to concentrate the various titanium minerals.

Most of the rutile, ilmenite, and leucoxene produced is processed into various upgraded products, with a minor quantity (1-2 percent) being used directly as coatings for welding electrodes and as a flux in smelter operations. Ilmenite is used in sand-blasting operations and more recently as a weighting agent in oil well drilling muds.

Beneficiation of ilmenite, leucoxene, and titanomagnetite leads to the production of either titania slag or synthetic rutile (upgraded ilmenite), both of which may be considered as upgraded raw material. Further processing of these materials, and of natural rutile, is needed to produce titanium dioxide (TiO_2) and titanium metal. These upgraded materials (titania slag and synthetic rutile) are discussed below.

Titania slag available on the world market is produced at Sorel, Canada (80 percent TiO_2 content), and at Richards Bay, South Africa (85-87 percent TiO_2 content). The slag is produced by reduction of ilmenite with carbon in an electric furnace. The high-titanium, low-iron slag is preferred over lower grade feedstock for titanium dioxide manufactured by the sulfate-route process (which utilizes sulfuric acid and a feedstock of ilmenite, leucoxene, or titania slag), because this slag reduces the quantity of sulfuric acid required and curtails waste disposal pollution. Japan, the Soviet Union, and China also produce slags of similar grade for use in local titanium-metal manufacture (Adams, 1984).

Synthetic rutile (upgraded ilmenite) produced from ilmenite has a TiO_2 content approaching that of natural rutile (that is, greater than 90 percent TiO_2). Production first started in the early 1970's, and plants are now located in Australia, India, Japan, Taiwan (currently not in operation), the United States, China, and the Soviet Union. In the most common method of production, the iron oxide content is reduced to the metal or ferrous state and then chemically leached away from the titanium (Adams, 1984). The product has a much greater TiO_2 content than the original ilmenite and may substitute for natural rutile in the production of titanium metal and in the manufacture of titanium dioxide pigment by the chloride-route process. In this process, chlorine is used, generally with a feedstock of natural or synthetic rutile.

The manufacture of titanium dioxide accounts for 95 percent of the world's titanium-mineral production (Lynd, 1985). In addition to the sulfate-route and the chloride-route processes, Du Pont has developed a process which allows the use of lower grade feedstocks such as high-grade ilmenite, leucoxene, or titania slag. The chloride-route process is now preferred in most developed countries, because it is highly automated, requires less manpower, and has lower levels of waste. The sulfate route is more common in less developed countries such as India and Mexico because of its lower capital outlay and technical requirements. Such countries have low labor costs and less strict pollution regulations (Adams, 1984).

The major use of titanium dioxide is as a pigment, but there are other important industrial applications. The various applications of titanium dioxide reflect its special properties, which include high refractive index which imparts considerable opacity or hiding power; high reflectivity which imparts great brightness and brilliant whiteness; chemical inertness which contributes to excellent color retention; and thermal stability over a wide range of temperatures. Titanium dioxide is non-toxic, nonfibrogenic, biologically inert, and has useful electrical properties (Adams, 1984).

The largest market for TiO_2 pigment is in the surface-coating industries, where it is used particularly in paint but also in varnish and lacquer. In all western countries, TiO_2 is the most widely used white pigment in paint. Surface-coating industries accounted for 62 percent of world TiO_2 pigment demand in 1984, the second largest market being the plastics industry (15 percent), and the third largest the paper industry (12 percent). In the United States, however, the paper industry consumes more TiO_2 pigment than the plastics industry (Callow, 1985). In addition to its use as a pigment in these three major industries, titanium dioxide is also consumed in small amounts in the manufacture of rubber, leather, ceramics, textiles, concrete, cosmetics, catalysts, glass fibers, and other products (Adams, 1984).

Approximately 4 percent of the world's annual production of titanium minerals, including 25 percent of the rutile production, goes to make titanium metal. Only in the Soviet Union and China is ilmenite used; all western producers use natural or synthetic rutile in the manufacture of titanium metal.

Titanium-metal ingots are produced in three stages which are often carried out at separate localities. The first stage involves the production of titanium tetrachloride ($TiCl_4$), which is used also in the chloride-route process for TiO_2 production. The second stage concerns the reduction of $TiCl_4$ by molten sodium (the Hunter process) or by molten magnesium (the Kroll process) to produce titanium sponge metal—so called "sponge" because of its appearance and high porosity. The third stage is consolidation of the sponge metal into ingots, which is normally done by vacuum-arc melting and may require several melts to remove trace impurities. Alloying elements are added at this stage for the production of titanium alloys. Scrap titanium metal, which is used in 35 to 40 percent of world ingot production, is also added at this stage (Lynd, 1985).

Of the total titanium metal produced in the world, approximately 30 percent is used as pure metal, 65 percent as titanium-based alloys (for example with minor amounts of vanadium or aluminum), and 5 percent as a minor additive in alloys based on aluminum, nickel, copper, or other metals (Adams, 1984).

Consumption of titanium metal and its alloys is in two broad markets: aerospace and industry. The aerospace market, which accounted for 45 percent of Western World titanium-metal consumption (60 percent of U.S. consumption) in 1983 (Adams, 1984; Lynd, 1985), primarily consists of commercial and military aircraft but also includes spacecraft and guided missiles. Titanium is used in airframe structural parts and in jet engine components because of its very high strength-to-weight ratio and its ability to maintain its mechanical properties at elevated temperatures.

The industrial market includes a diverse group of markets where titanium metal is used for its resistance to corrosion, its lack of toxicity, and other properties. The 55 percent of 1983 Western World consumption of titanium metal in the industrial market was chemical and desalination plants, 28 percent; power station equipment, 11 percent; and food, medical, and marine applications, most of the remaining 16 percent (Adams, 1984).

SUPPLY ASPECTS

At the end of 1985, world capacity for titanium dioxide production in about 52 separate plants in 24 countries was 2.7 million metric tons. The United States accounted for approximately 30 percent of the total; the Federal Republic of Germany, 12 percent; the United Kingdom, 9 percent; Japan, 9 percent; and France, 6 percent (Lynd, 1985). Four companies through their international subsidiaries and affiliates account for 62 percent of the world production capacity; these are Du Pont, Tioxide Group, SCM Corp, and NL Industries (Callow, 1985). Production by these companies is partly from raw materials, including titania slag and synthetic rutile, imported from mines and plants in countries such as Australia, Canada, and South Africa. The major net exporters of titanium dioxide are the Federal Republic of Germany, France, Belgium, and Japan. The United States is a net importer (Lynd, 1985).

In the past 15 years, world titanium dioxide production capacity has been comfortably in excess of demand (Adams, 1984). During 1984 and 1985, however, the gap between demand and supply diminished substantially, so that over the next few years demand will exceed supply. The industry is now considered to have reached maturity. The U.S. Bureau of Mines forecasts that for the United States, the average annual growth rate for titanium dioxide demand to the year 2000 will be 1.8 percent. The forecast is somewhat higher for the rest of the world, and particularly higher for developing countries (Lynd, 1985).

The 1985 world titanium sponge production capacity was estimated at 132,000 metric tons, of which the Soviet Union accounted for 39 percent; Japan, 29 percent; the United States, 26 percent; the United Kingdom, 4 percent; and China, 2 percent. There are 20 separate production plants located in these 5 countries. Three companies account for 58 percent of Western World titanium sponge production: Osaka Titanium Corp, Toho Titanium, and Titanium Metals Corp of America (Adams, 1984). None of the Western World titanium sponge producers own their source of raw material. They must import rutile from countries such as Australia, Sierra Leone, and South Africa.

Titanium-metal demand has varied widely in the past as a result of changes in the requirements for military and commercial aircraft. Demand from nonaerospace industries has also been difficult to forecast. This situation has led to periods of undersupply followed by periods of oversupply. Annual growth in demand for titanium metal in the United States to the year 2000 has been estimated at 5.5 percent (Lynd, 1985).

Several points regarding the supply of titanium raw materials, titanium dioxide, and titanium metal are noteworthy:

- Although they have a large share of the export markets, the traditional major exporters of raw material, for example, Australia, Canada, and Norway, have been affected by the newly established exporters, such as Sierra Leone and South Africa.
- Because some titanium mines—for example those in the Soviet Union, China, Brazil, and India—are government owned, production might be maintained when normal market forces would require their closure.
- Additions to the United States' strategic stockpile may provide stimulus to the titanium-metal industry. As of September 1986, the inventories were 37 percent of the goal of 96,000 metric tons of rutile and 13 percent of the goal of 177,000 metric tons of sponge metal (Lynd, 1987a, b).
- Brazil may emerge in the near future as a major producer of titanium-bearing minerals through its vast reserves of anatase (90 percent TiO_2). A titanium dioxide pigment plant having a capacity of 200,000 metric tons per year is to be constructed at Araxa and will use anatase as its feedstock (Industrial Minerals, 1984).
- There are no completely satisfactory substitutes for titanium metal or titanium dioxide. The metal may face competition in the future, however, from new boron and carbon fiber materials. In the pigment industry, cheaper substitutes, such as zinc oxide, lithopone, calcium carbonate, and others, may be used in place of titanium dioxide, although they result in an inferior product.
- Future demand for titanium raw materials will continue to depend essentially on the titanium dioxide pigment industry. This industry requires 95 percent of the world's titanium-ore production for raw material, while the metal industry requires just 4 percent.

DISTRIBUTION OF TITANIUM DEPOSITS

The world maps in figures 2 and 3 show the locations of the 86 major ilmenite and 52 major rutile deposits and districts in the inventory. In this report, leucoxene and titanomagnetite[2] deposits are grouped with ilmenite deposits, and anatase with rutile. Many of the deposits contain both ilmenite and rutile giving a total of 96 titanium mineral deposits. They are located in relatively few (21) countries on all continents but Antarctica, although identified deposits are scarce in central and north Africa and South America exclusive of Brazil. Also noteworthy is the fact that many of the deposits, as in Australia, South Africa, Canada, and China, are grouped together in provinces. Figures 4 and 5 show the economic class of each country having a major deposit.

Titanium minerals are currently produced from both secondary placer deposits and primary magmatic deposits. However, there exists a third deposit type, laterite deposits. The secondary placer deposit type includes the greatest number of selected deposits with 59 out of the total 96. These placer deposits are composed of generally unconsolidated sands that are enriched in heavy minerals. The great majority of secondary placer deposits are marine in origin; the remainder are alluvial. 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 Cretaceous-Tertiary deposits of Dnepropetrovsk and Zhitomir in the Soviet Union, are important. Most placer deposits have grades in the order of 5 to 10 percent ilmenite and 1 percent rutile. Sand deposits containing less than

[2]Titanomagnetite reserves are included only where a bulk oxide concentrate exceeds an economic cutoff figure for TiO_2 content (approximately 25 percent in industrial market countries); where ilmenite occurs as discrete and separate grains within the magnetite; or where a byproduct like vanadium can be economically recovered necessitating chemical destruction of the magnetite.

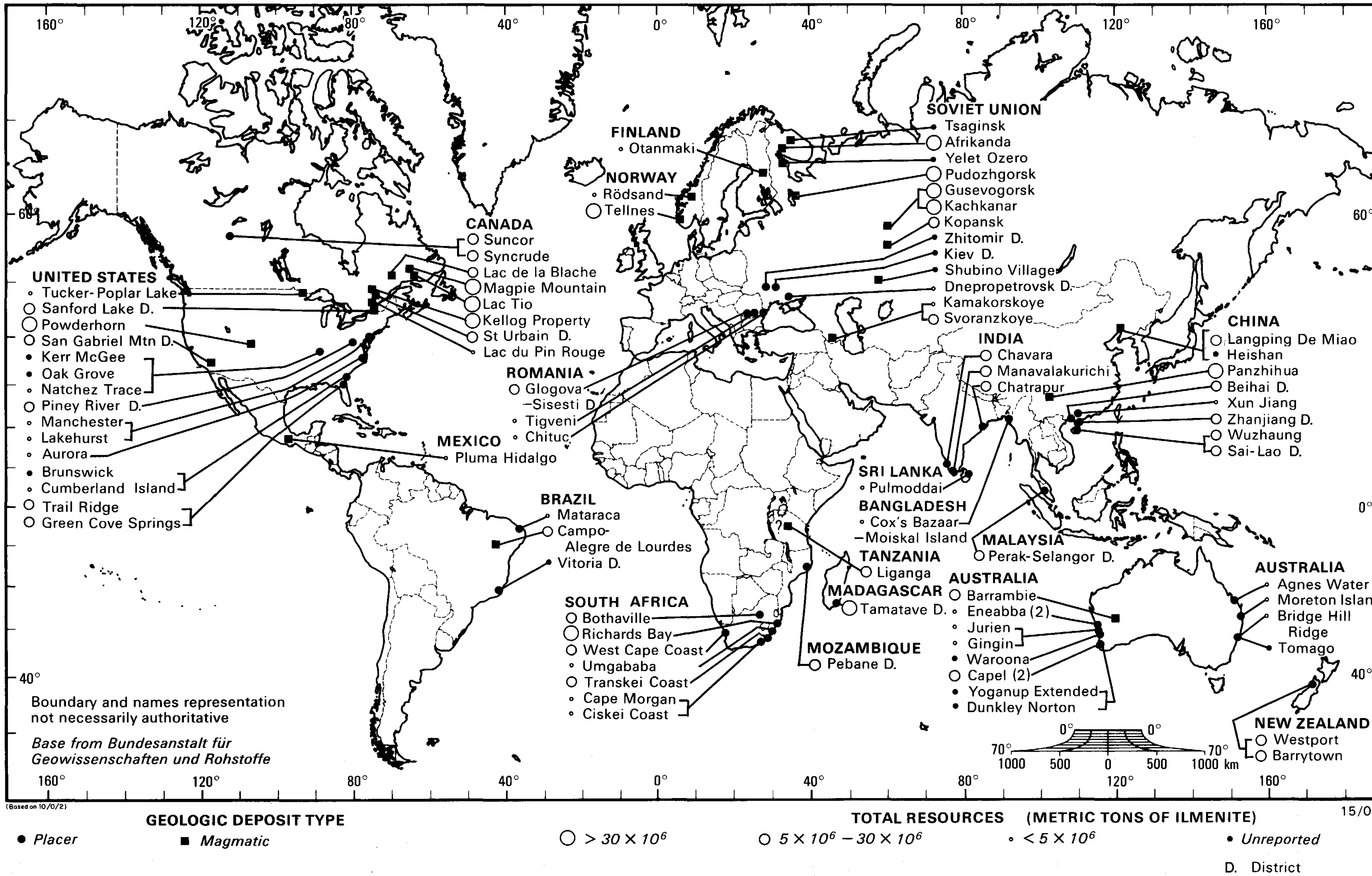
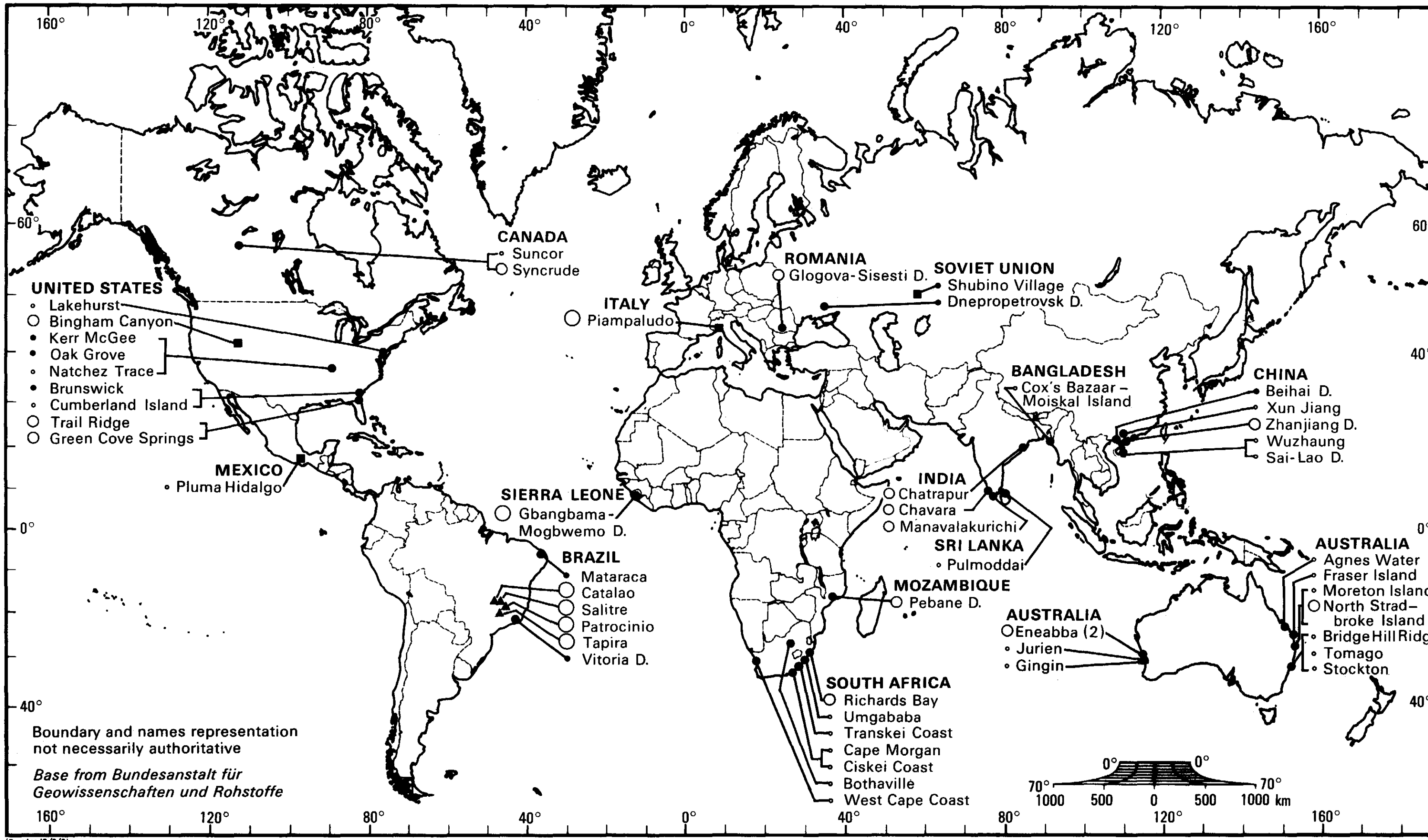


Figure 2.—Location, geologic deposit type, and total resources of the world's major ilmenite deposits and districts. Location names are from the tables in Part II.



(Based on 10/0/2)

15/0/7

GEOLOGIC DEPOSIT TYPE

● *Placer* ■ *Magmatic* ▲ *Lateritic*

TOTAL RESOURCES (METRIC TONS OF RUTILE)

O *> 10 × 10⁶* o *10⁶–10 × 10⁶* ∘ *<10⁶* • *Unreported*

D. District

Figure 3.—Location, geologic deposit type, and total resources of the world's major rutile deposits and districts. Location names are from the tables in Part II.

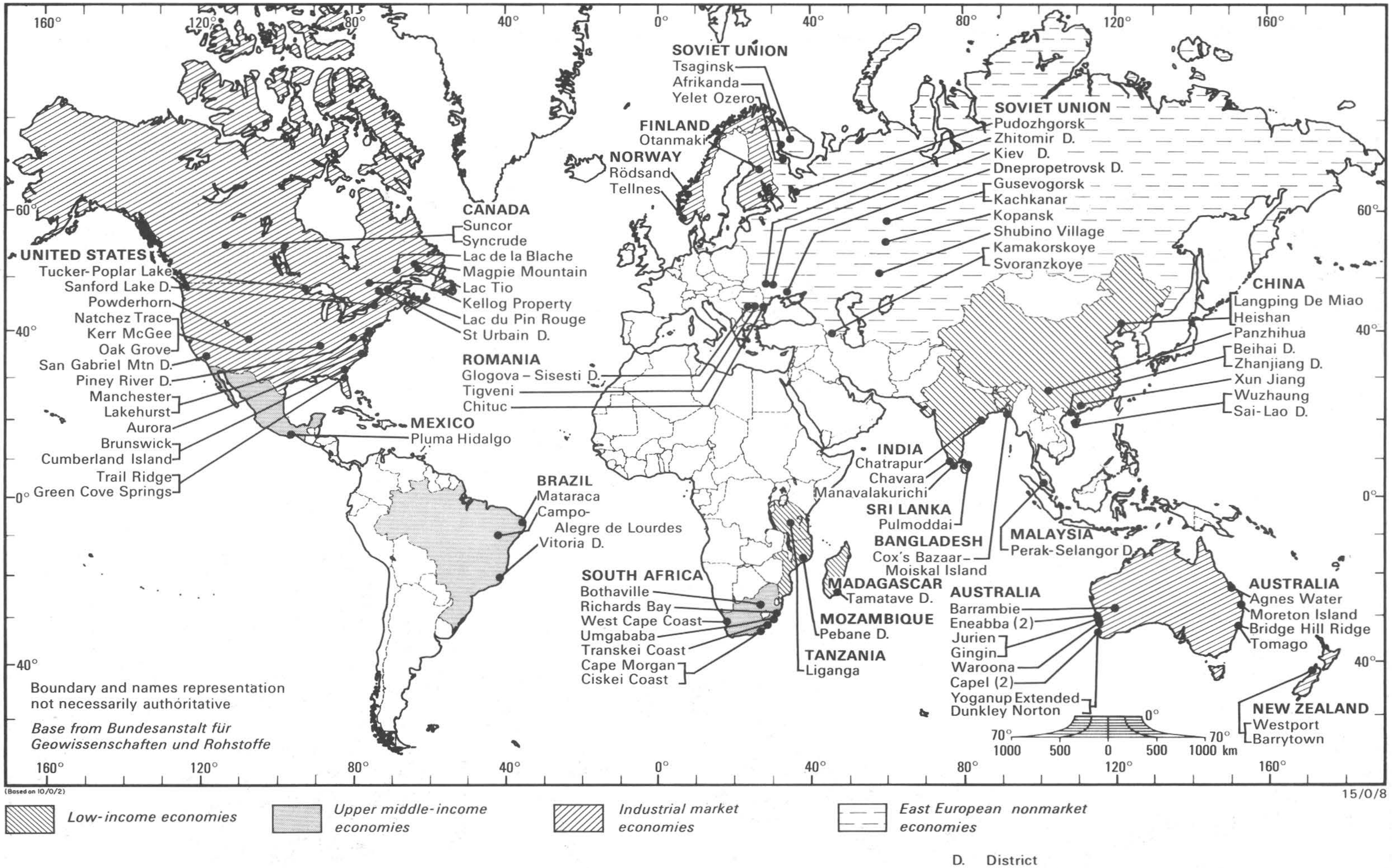


Figure 4.—Economic classification of the World Bank (1985, p. 174–175) for countries containing major ilmenite deposits and districts. Location names are from the tables in Part II.

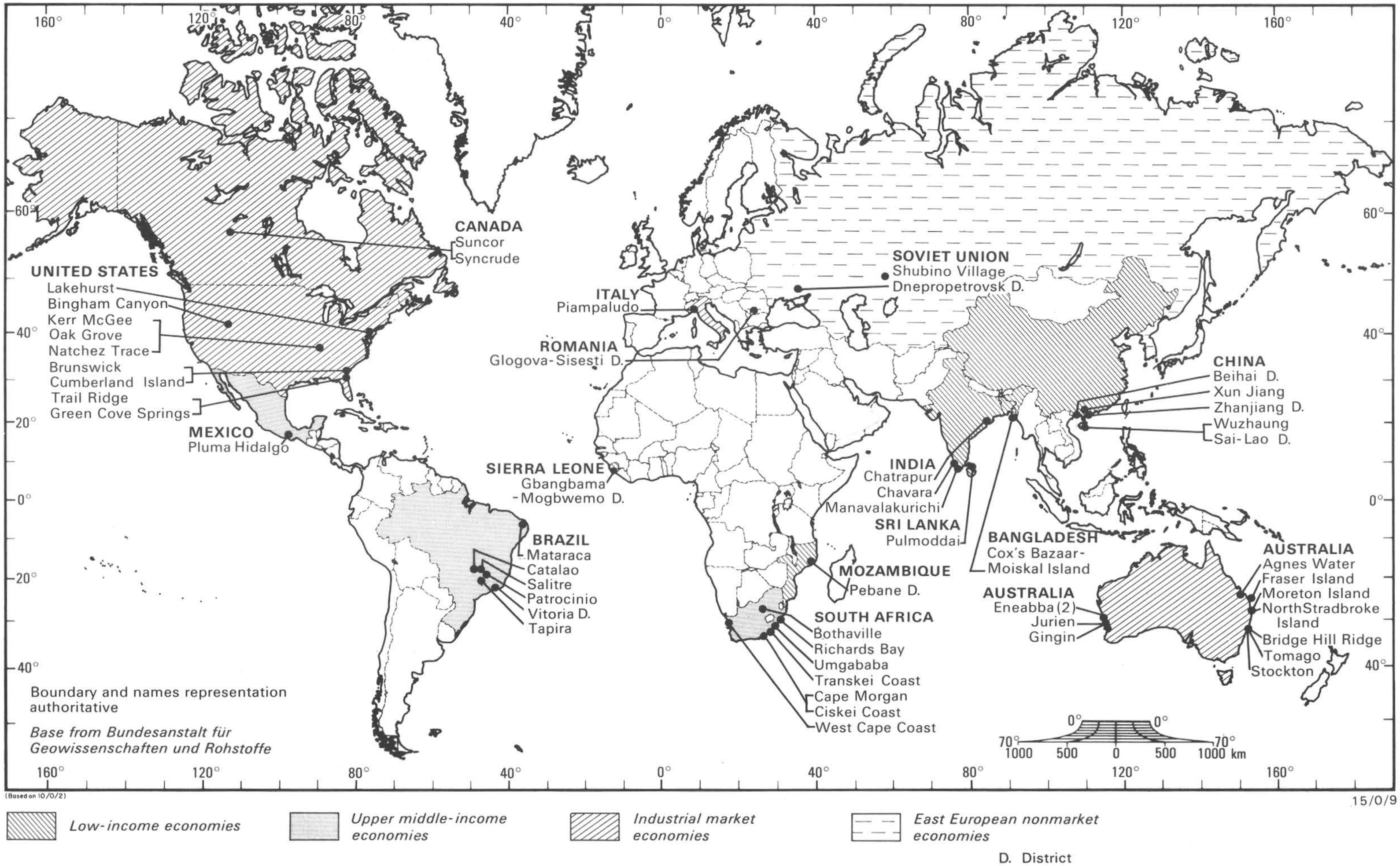


Figure 5.—Economic classification of the World Bank (1985, p. 174–175) for countries containing major rutile deposits and districts. Location names are from the tables in Part II.

1 percent ilmenite (as in China) and less than 0.5 percent rutile (as in Australia) may be economic, but grades may be much higher as at Pulmoddai, Sri Lanka (73 percent ilmenite, 11 percent rutile). The easily minable character of some rutile beach placers, such as those in eastern Australia, allows mining of grades below the average titanium concentration of the Earth's crust (Brooks, 1976, p. 149; Force, 1976, p. 8).

The remainder of the deposits which contain most of the world's resources are predominantly magmatic which, for this report, includes metamorphic deposits (Piampaludo, Italy, and Shubino Village, Soviet Union). The host rocks are typically basic or ultrabasic and are frequently associated with anorthosites (Lac Tio, Canada; Tellnes, Norway; and Sanford Lake, United States); others are associated with alkaline igneous rocks (Afrikanda, Soviet Union, and Powderhorn, United States). Most are Precambrian in age, but some are of Paleozoic age. The mineralization may be massive, occurring as lenses, layers, or seams, or it may be disseminated. In magmatic deposits, titanomagnetite, often occurring in close association with ilmenite, is the common titanium-bearing mineral; rutile is not common. Economic deposits of this type generally have a grade between 10 to 30 percent TiO_2, although some deposits in the Soviet Union are being mined with as little as 1 to 2 percent TiO_2.

Four deposits in Brazil are the only known economic titanium-laterite deposits in the world. These deposits are derived from former alkalic igneous rocks that underwent intense tropical weathering to leave a lateritic mantle that is highly enriched in titanium (approximately 20 percent TiO_2 as anatase).

TITANIUM RESOURCES

Total R1E resources in the world's major deposits are as follows: ilmenite, 839 million metric tons; rutile, 28 million metric tons; and anatase, 96 million metric tons. The world total of reported "all other R1 and R2" resources (R1M, R1S, R2E, and R2S) is as follows: ilmenite, 1,835 million metric tons; rutile, 50 million metric tons; and anatase, 57 million metric tons. These figures are based on data reported in table 10 of Part II.

Table 2 shows the grouping of these resources by deposit type. Magmatic deposits contain the bulk of the ilmenite resource with 74

TABLE 2.—*Titanium resources in, and cumulative production from, the world's major titanium deposits and districts, by geologic deposit type and resource category*

[Figures are based on data as reported in table 10 of Part II and are in million metric tons; figures in parentheses denote percentage of each mineral accounted for by each deposit type]

Deposit type[1]	No. of records	Titanium mineral	Resource category: R1E[2]		All other R1 and R2[3]		Cumulative production	
Magmatic	33	Ilmenite[4]	625	(74)	1,625	(89)	57.0	(61)
		Rutile	6	(22)	16	(32)	0	(0)
Placer	59	Ilmenite	214	(26)	210	(11)	36.9	(39)
		Rutile	21	(78)	34	(68)	5.9	(100)
Lateritic	4	Anatase	96	(100)	57	(100)	.03	(100)
	—	Totals						
Total	96	Ilmenite	839	(100)	1,835	(100)	93.9	(100)
		Rutile	28	(100)	50	(100)	5.9	(100)
		Anatase	96	(100)	57	(100)	.03	(100)

[1] Deposit types of the world's major titanium deposits are shown in figures 2 and 3.
[2] Reliable estimates from identified deposits with economically exploitable resources (fig. 1).
[3] Includes resources in the R1M, R1S, R2E, and R2S categories (fig. 1).
[4] Ilmenite includes equivalent titanomagnetite, leucoxene, perovskite, and titania slag.

percent of R1E resources and 89 percent of all other R1 and R2 resources. The remaining ilmenite resource is in placer deposits. The situation is the reverse for rutile, however, where placer deposits account for 78 percent of R1E resources and 68 percent of all other R1 and R2 resources. If anatase and rutile resources are grouped, then the laterite deposits of Brazil account for 78 percent of the R1E rutile resources, while placer deposits and magmatic deposits account for 17 percent and 5 percent, respectively. The laterite deposits would account for 53 percent of all other R1 and R2 rutile resources.

The distribution of the world's titanium resources in major deposits by resource category and by country is shown in table 3 and figure 6. China has the largest share of the world's R1E ilmenite resources, with 26 percent of the total, closely followed by the Soviet Union with 25 percent; then Norway, 15 percent; South Africa, 10 percent; Canada, 9 percent; and India, 7 percent. China and Canada have the major share of the world's other R1 and R2 ilmenite resources with 50 percent and 30 percent of the total, respectively.

Australia has the largest share of the world's R1E rutile resources with 24 percent of the total, but a portion of these resources is currently unavailable for mining because of alternate land uses. Italy, South Africa, and India each have approximately 15 to 20 percent of R1E rutile resources. Sierra Leone has 47 percent of the

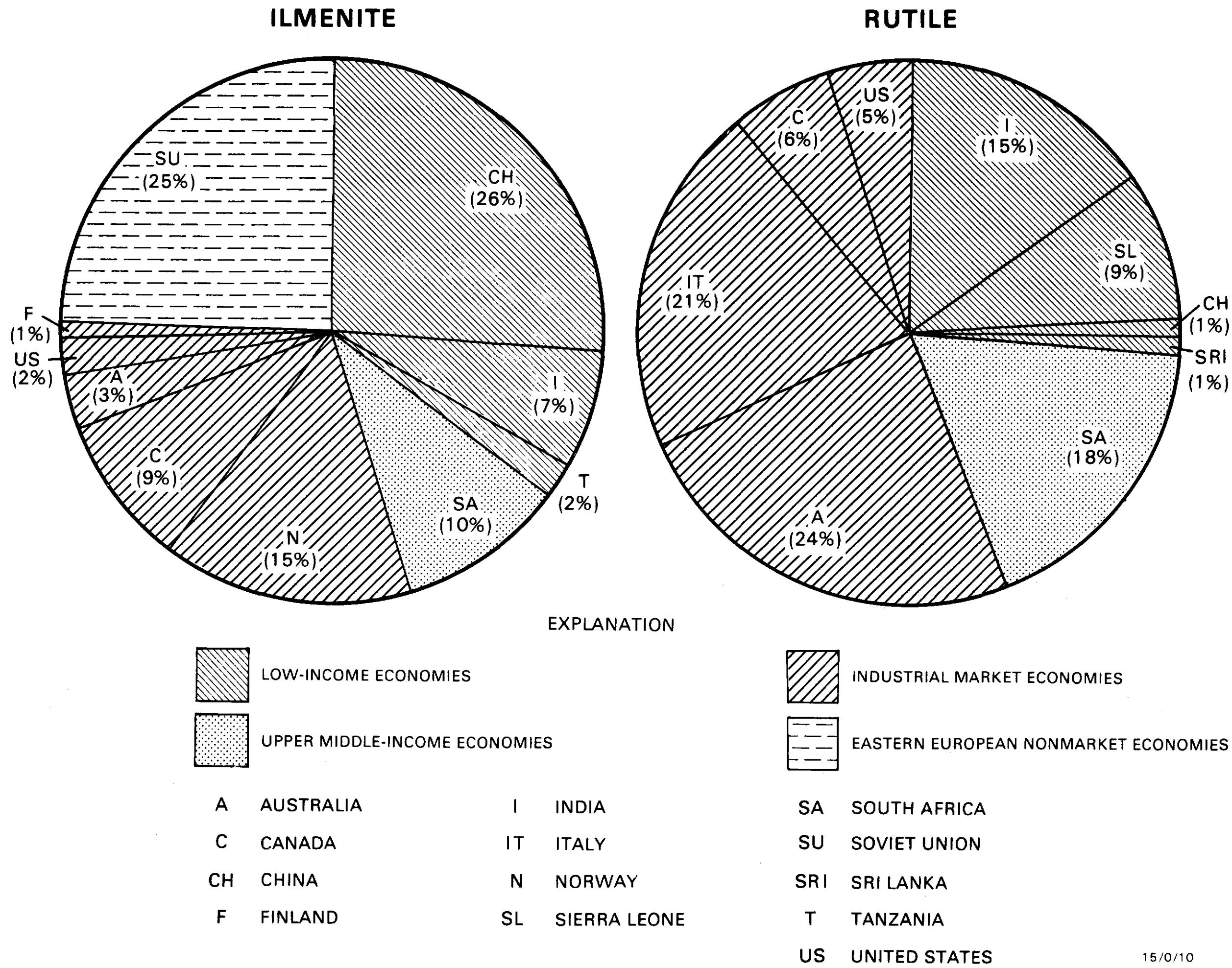


Figure 6.—Distribution of ilmenite and rutile identified economic resources (R1E) in the world's major deposits and districts, by country and economic class of country. Economic classes are based primarily on GNP per capita (World Bank, 1985, p. 174–175). Two additional classes—lower middle-income economies and high-income oil exporters—are not shown because those countries do not have reported titanium R1E resources. Ilmenite includes equivalent titanomagnetite, leucoxene, and perovskite. Countries in the ilmenite inventory (fig. 2) that do not have reported ilmenite R1E resources are Bangladesh, Brazil, Malaysia, Mexico, Madagascar, New Zealand, Romania, and Sri Lanka. Rutile does not include anatase. Countries in the rutile inventory (fig. 3) that do not have reported rutile R1E resources are Bangladesh, Brazil, Mozambique, Romania, and the Soviet Union.

world's rutile resources in other R1 and R2 categories. Brazil has major significance if its anatase resources are included with rutile, but such figures are not included in table 3.

Distribution of the world's resources by economic class of country is shown in table 4 and in figure 6. Countries in each class are shown in figures 4 and 5.

The major share of both R1E and other R1 and R2 resources of ilmenite is in the low-income economy countries (35 percent and 53 percent, respectively), with China and India the dominant countries in this class. Industrial market economy countries rank second in both resource categories, followed by the eastern European nonmarket economy countries and the upper middle-income economy countries. The lower middle-income economy countries have no reported resources. The industrial market economy countries have the largest share of the world's R1E resources of rutile with 56 percent of the total. Low-income economy countries have 25 percent of the R1E rutile resources, and over 50 percent of the other R1 and R2 resource categories. Upper middle-income econ-

TABLE 3.—*Ilmenite and rutile resources in the world's major deposits and districts, by country and resource category*

[Includes only countries having major ilmenite and rutile deposits and districts in the International Strategic Minerals Inventory. See figures 2 and 3. Figures are based on data as reported in table 10 of Part II and are in million metric tons; figures may not add to totals shown due to rounding. Figures in parentheses are percent of each mineral accounted for by each resource category. N.r.=None reported]

Country	Ilmenite[1]				Rutile[2]			
	R1E[3]		All other R1 and R2[4]		R1E[3]		All other R1 and R2[4]	
Australasia								
Australia	27	(3)	3	(0)	6.7	(24)	0.6	(1)
New Zealand	N.r.		31	(2)	N.r.		N.r.	
North America								
Canada	75	(9)	541	(30)	1.8	(6)	N.r.	
Mexico	N.r.		N.r.		N.r.		N.r.	
United States	19	(2)	77	(4)	1.5	(5)	5.5	(11)
South America								
Brazil	N.r.		24	(1)	N.r.		N.r.	
Europe								
Finland	5	(1)	N.r.		N.r.		N.r.	
Italy	N.r.		N.r.		6	(21)	12	(24)
Norway	128	(15)	N.r.		N.r.		N.r.	
Romania	N.r.		8	(0)	N.r.		1.7	(3)
Soviet Union	211	(25)	118	(6)	N.r.		N.r.	
Africa								
Mozambique	N.r.		30	(2)	N.r.		2	(4)
South Africa	85	(10)	50	(3)	5.1	(18)	2.4	(5)
Sierra Leone	N.r.		N.r.		2.5	(9)	23	(47)
Tanzania	13	(2)	N.r.		N.r.		N.r.	
Madagascar	?		?		N.r.		N.r.	
Asia								
Bangladesh	N.r.		N.r.		N.r.		N.r.	
China	216	(26)	910	(50)	0.2	(1)	N.r.	
India	58	(7)	33	(2)	4.2	(15)	1.8	(4)
Malaysia	N.r.		10	(1)	N.r.		N.r.	
Sri Lanka	2	(0)	N.r.		0.3	(1)	N.r.	
Total	839	(100)	1,835	(100)	28	(100)	50	(100)

[1] Ilmenite includes equivalent titanomagnetite, leucoxene, and perovskite.
[2] Rutile does not include anatase from Brazil.
[3] Reliable estimates from identified deposits with economically exploitable resources (fig. 1).
[4] Includes resources in the R1M, R1S, R2E, and R2S categories (fig. 1).

omy countries have a minor share of rutile resources, but if Brazilian anatase were included, this class would be by far the most important.

The distribution of the world's ilmenite and rutile resources according to mining method and economic class of country is shown in table 5. Most of the resources of both minerals occur in deposits that are currently being surface mined. Only a very minor proportion of the resources occurs in deposits being mined underground, the Otanmaki deposit in Finland being the most important.

Table 2 indicates that the total ilmenite and rutile resources in the world's major deposits are many times that of the total reported cumulative production from these deposits. Using the estimates of R1E resources for these two minerals

TABLE 4.—*Ilmenite and rutile resources in the world's major deposits and districts, by economic class of country and resource category*

[Figures are in million metric tons and are based on data as reported in table 10 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[1] class	No. of records	Resource category[2]			
		R1E		All other R1 and R2	
Ilmenite[3]					
Low-income	16	290	(35)	973	(53)
Upper middle-income	12	85	(10)	84	(5)
Industrial market	42	253	(30)	652	(36)
Eastern European nonmarket	16	211	(25)	126	(7)
Total	86	839	(100)	1,835	(100)
Rutile[4]					
Low-income	12	7	(25)	27	(53)
Upper middle-income	14	5	(18)	2	(4)
Industrial market	23	16	(56)	20	(39)
Eastern European nonmarket	3	N.r.		2	(4)
Total	52	28	(100)	50	(100)

[1] Based principally on GNP per capita and, in some instances, other distinguishing economic characteristics (World Bank, 1985, p. 174-175). Countries where major ilmenite deposits or districts occur are, by class: low-income economies—Bangladesh, China, India, Madagascar, Mozambique, Sri Lanka, and Tanzania; upper middle-income economies—Brazil, Malaysia, Mexico, and South Africa; industrial market economies—Australia, Canada, Finland, New Zealand, Norway, and the United States; eastern European nonmarket economies—Romania and the Soviet Union. Countries where major rutile deposits or districts occur are, by class: low- income economies—Bangladesh, China, India, Mozambique, Sierra Leone, and Sri Lanka; upper middle-income economies—Brazil, Mexico, and South Africa; industrial market economies—Australia, Canada, Italy, and the United States; eastern European nonmarket economies—Romania and the Soviet Union. Two additional economic classes, lower middle-income economies and high-income oil exporters, are not listed because those countries do not have identified major ilmenite or rutile deposits.
[2] Categories are defined in figure 1.
[3] Includes equivalent titanomagnetite, leucoxene, and perovskite.
[4] Does not include anatase from Brazil.

(table 2) and production at the 1985 rates (see table 6), ilmenite resources would be expected to last for about another 150 years and rutile resources for another 65 years. If Brazilian anatase is included with the rutile resources, production could be supported at the current rate for about another 300 years. In addition, the world's ilmenite and rutile resources in other R1 and R2 resource categories and further discoveries could extend production life significantly.

TITANIUM MINERAL PRODUCTION

Total world cumulative production during the period 1925 through 1985 was 126.0 million metric tons of ilmenite[3] and 10.1 million metric

[3] Ilmenite includes equivalent titania slag, leucoxene, and titanomagnetite. Method of calculation is to convert these products to an equivalent quantity of TiO_2, then convert the TiO_2 to an equivalent quantity of ilmenite (50 percent TiO_2). Refer to table 10 of Part II for the reported titanium products from each major deposit or district.

TABLE 5.—*Ilmenite and rutile resources in the world's major deposits and districts, by mining method and economic class of country; and ilmenite and rutile cumulative production, by mining method*

[Resources include those in R1 and R2 categories (fig. 1); figures are based on data as reported in table 10 of Part II and are in million metric tons; figures may not add to totals shown due to rounding. N.r.=None reported]

Economic class[1]	Mining method			
	Surface	Under-ground	Never mined	Not reported
	Ilmenite[2]			
Low-income	1,244	N.r.	17	2
Upper middle-income	117	N.r.	52	N.r.
Industrial market	338	7	561	N.r.
Eastern European nonmarket	76	14	21	227
Total	1,775	21	651	229
Cumulative production	90.1	3.5	N.r.	0.
	Rutile[3]			
Low-income	34.0	N.r.	N.r.	N.r.
Upper middle-income	6.9	N.r.	0.5	N.r.
Industrial market	10	N.r.	24.4	N.r.
Eastern European nonmarket	N.r.	N.r.	1.7	N.r.
Total	50	N.r.	27	N.r.
Cumulative production	5.9	N.r.	N.r.	N.r.

[1] Based principally on GNP per capita and, in some instances, other distinguishing economic characteristics (World Bank, 1985, p. 174-175). Countries where major ilmenite deposits or districts occur are, by class: low-income economies-Bangladesh, China, India, Madagascar, Mozambique, Sri Lanka, and Tanzania; upper middle-income economies—Brazil, Malaysia, Mexico, and South Africa; industrial market economies—Australia, Canada, Finland, New Zealand, Norway, and the United States; eastern European nonmarket economies—Romania and the Soviet Union. Countries where major rutile deposits or districts occur are, by class: low-income economies—Bangladesh, China, India, Mozambique, Sierra Leone, and Sri Lanka; upper middle-income economies—Brazil, Mexico, and South Africa; industrial market economies—Australia, Canada, Italy, and the United States; eastern European nonmarket economies—Romania and the Soviet Union. Two other economic classes, lower middle-income economies and high-income oil exporters, are not listed because those countries do not have identified major ilmenite or rutile deposits.

[2] Includes equivalent titanomagnetite, leucoxene, perovskite, and titania slag.

[3] Does not include anatase from Brazil.

TABLE 6.—*Estimated annual (1985) and cumulative (1925-85) production of ilmenite and rutile by country*

[Figures are in thousand metric tons; figures may not add to totals shown due to rounding. Figures in parentheses are percent of column totals. N.r.=None reported]

Country[1]	Ilmenite				Rutile			
	Annual production		Cumulative production[2]		Annual production		Cumulative production[2]	
Australia[3]	1,432	(25)	23,217	(18)	212	(52)	8,132	(81)
Canada[4]	1,350	(24)	28,570	(23)	N.r.		N.r.	
Norway	735	(13)	18,437	(15)	N.r.		2	(0)
South Africa[4]	610	(11)	2,951	(2)	62	(15)	434	(4)
Soviet Union	445	(8)	4,535	(4)	10	(2)	140	(1)
United States[5]	290	(5)	25,730	(20)	30	(7)	560	(6)
Malaysia	249	(4)	5,083	(4)	N.r.		N.r.	
India	170	(3)	8,640	(7)	7	(2)	113	(1)
China	140	(2)	730	(1)	N.r.		N.r.	
Sri Lanka	115	(2)	1,677	(1)	9	(2)	115	(1)
Brazil	76	(1)	457	(0)	.7	(0)	25	(0)
Finland	53	(1)	4,180	(3)	N.r.		N.r.	
Romania	6	(0)	17	(0)	N.r.		N.r.	
Madagascar	N.r.		371	(0)	N.r.		N.r.	
Mozambique	N.r.		12	(0)	N.r.		N.r.	
Mexico	N.r.		.4	(0)	N.r.		N.r.	
Sierra Leone	N.r.		N.r.		81	(20)	532	(5)
Others[6]	.3	(0)	1,362	(1)	N.r.		24	(0)
Total	5,671	(100)	125,968	(100)	412	(100)	10,077	(100)

[1] Includes all countries with major ilmenite or rutile deposits or districts in the International Strategic Minerals Inventory except for Bangladesh, Italy, New Zealand, and Tanzania which had no reported ilmenite or rutile production for the years 1925 through 1985.

[2] Calculated from reported production figures (U.S. Bureau of Mines 1926-87; British Geological Survey, 1987).

[3] Includes leucoxene.

[4] Includes equivalent of titania slag (Canada, average 71 percent TiO_2 through 1983, 80 percent TiO_2 thereafter; South Africa, 85 percent TiO_2).

[5] Majority of U.S. rutile production figures withheld; figures are estimates calculated from available data.

[6] Countries not included in this inventory (in order of importance): Ilmenite—Spain, Senegal, Egypt, Gambia, Portugal (current producer), and Thailand. Rutile—Cameroon, Egypt, and Senegal.

tons of rutile (U.S. Bureau of Mines, 1926-34 and 1933-87; British Geological Survey, 1987). Over 99 percent of both of these totals is accounted for by the 21 countries listed in this inventory. The current annual (1985) world production is 5.7 million metric tons of ilmenite and about 0.4 million metric tons of rutile. Table 6 and figures 7 and 8 present the production of ilmenite and rutile by individual countries.

Australia and Canada are the major producers of ilmenite; in 1985, output from each country amounted to about 1.4 million metric tons (49 percent of the total world output). Norway ranks next (13 percent), followed by South Africa (11 percent), the Soviet Union (10 percent), the United States (5 percent), and Malaysia (4 percent). Australia is by far the dominant producer of rutile with 212,000 metric tons in 1985 (52 percent of world output), with Sierra Leone (20 percent), South Africa (15 percent), the United States (7 percent), and the Soviet Union (2 percent) the next most important producers.

Over the period 1940 to 1970, there was an average increase per decade of 140 percent in ilmenite production and 330 percent in rutile production, but over the decade 1970 to 1980, the production increase was only 45 percent for ilmenite and 5 percent for rutile. From 1980 to 1985, ilmenite production decreased by 8 percent and rutile production decreased by 14 percent. Several important conclusions can be drawn from the patterns of world production shown in figures 7 and 8:

- Production of ilmenite is about 12 times greater than that of rutile (5 to 7 times in terms of TiO_2).
- During the period 1930 to 1985 total annual world production of ilmenite has increased from 48,000 metric tons to 5,671,000 metric tons or about 120 times. Annual production of rutile increased from 400 metric tons to 412,000 metric tons or about 1,000 times, but rutile is only

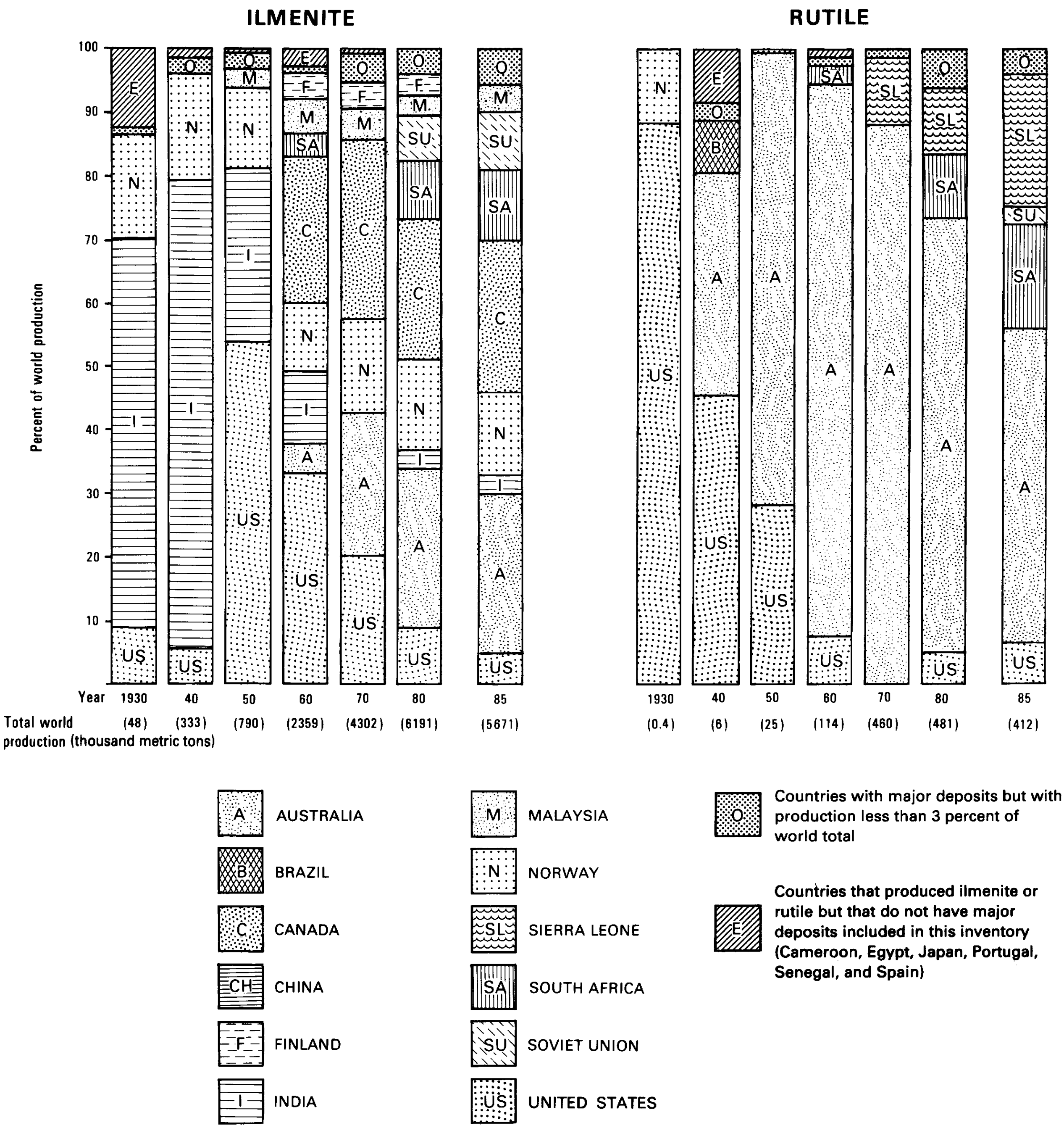
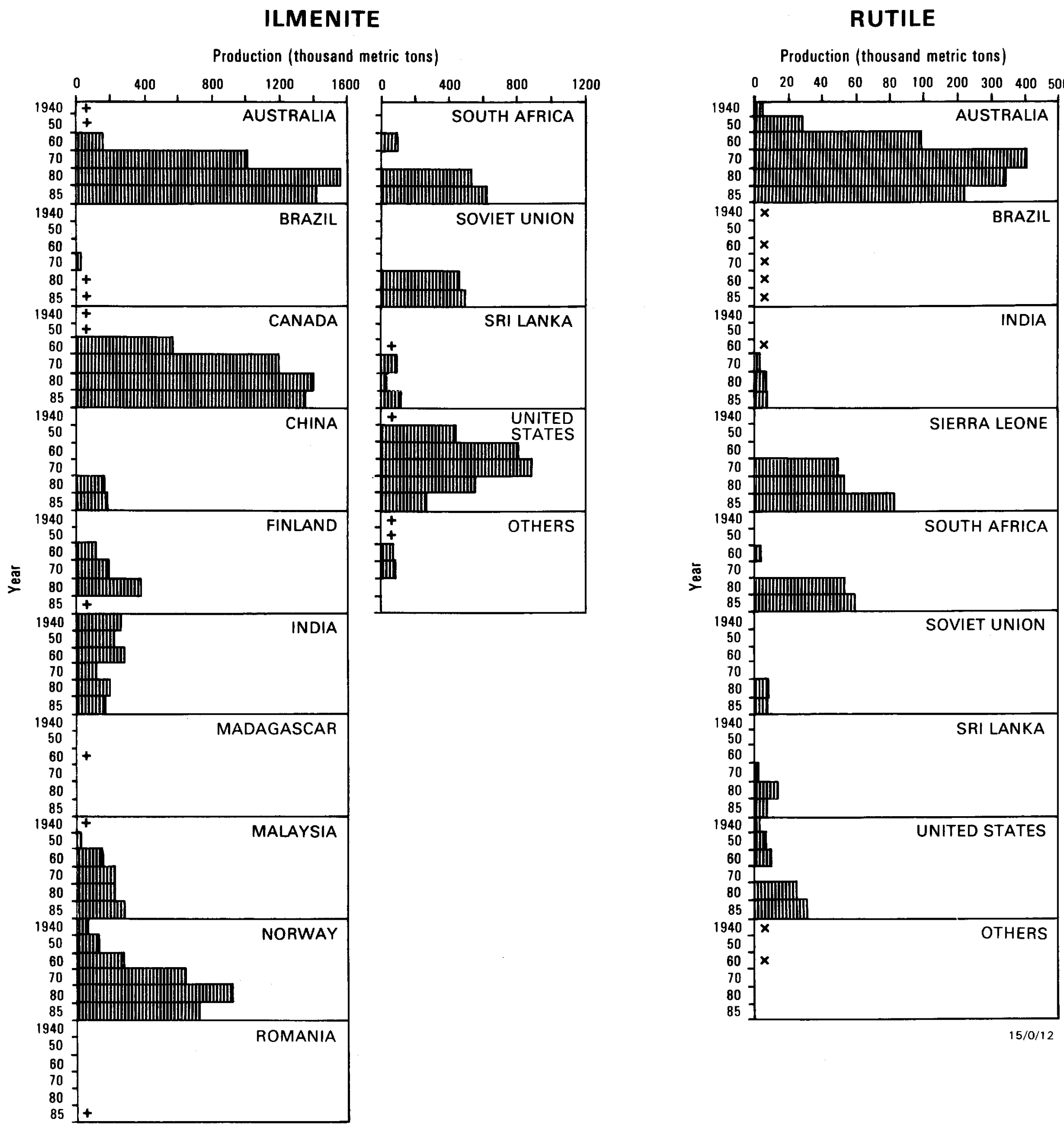


Figure 7.—Distribution of total world production of ilmenite and rutile, by country; selected years 1930–85 (U.S. Bureau of Mines, 1926–87; British Geological Survey, 1987). Values for the United States are approximate.



EXPLANATION

+	PRODUCTION LESS THAN 20,000 METRIC TONS BUT GREATER THAN 1,000 METRIC TONS.	NOTE:	CHANGE OF SCALE AT 100,000 METRIC TONS.
		×	PRODUCTION LESS THAN 2,000 METRIC TONS.
OTHERS	COUNTRIES NOT INCLUDED IN THIS INVENTORY (EGYPT, JAPAN, PORTUGAL, SENEGAL, AND SPAIN)	OTHERS	COUNTRIES NOT INCLUDED IN THIS INVENTORY (CAMEROON, EGYPT, AND NORWAY)

Figure 8.—Ilmenite and rutile production, by country; selected years 1940–85 (U.S. Bureau of Mines, 1942–87); British Geological Survey, 1987). Ilmenite includes equivalent titania slag (Canada and South Africa) and leucoxene (Australia and the United States). Values for the United States are approximate.

7.5 percent of the total amount of titanium raw materials (ilmenite and rutile) produced.

- India was a major ilmenite producer in 1930 and 1940 but is now of relatively minor importance.
- The United States was a major rutile producer in 1930, 1940, and 1950 and a major ilmenite producer in 1950, 1960, and 1970, but present production is of moderate significance.
- Australia has been a major rutile producer since 1940, accounting for nearly 90 percent of world production in 1960 and 1970. Australia now accounts for 50 percent of world production.
- Sierra Leone emerged as a major rutile producer in 1970 and is increasing in importance.
- The number of countries having 3 percent or more of world production of each mineral has steadily increased over the period shown. Figure 7 shows that these major ilmenite-producing nations have increased from 4 to 8, while major rutile-producing nations have increased from 2 to 5.

Figure 9 shows that in 1980 world ilmenite and rutile production was concentrated in relatively few countries. The top four ilmenite-producing countries accounted for 71 percent of the world's ilmenite production, while the top four rutile-producing countries accounted for 94 percent of the world's rutile production in 1980. The top eight producing countries provided 94 percent the ilmenite and 100 percent of the rutile.

Current (1985) annual world production and 1925 to 1985 cumulative production grouped by World Bank economic class of country are shown in table 7. In the case of ilmenite, the industrial market economy countries account for the major part of both the current and cumulative production totals (68 percent and 80 percent, respectively); upper middle-income economy countries are significant in terms of current production (17 percent). For rutile, the industrial market economy countries again account for the major share of current world production (59 percent) and more particularly in the cumulative production (86 percent). Both low-income and upper middle-income economy countries have significant proportions of current world rutile production (24 percent and 15 percent, respectively).

Reported cumulative production of ilmenite and rutile from the world's major deposits currently in production, according to geologic deposit type, is shown in table 2. Sixty-one percent of the ilmenite production (57.0 million metric tons) has come from magmatic deposits, and 100 percent of the rutile production (5.9 million metric tons) has come from placer deposits. An insignificant amount of anatase has been produced from Brazilian laterite deposits.

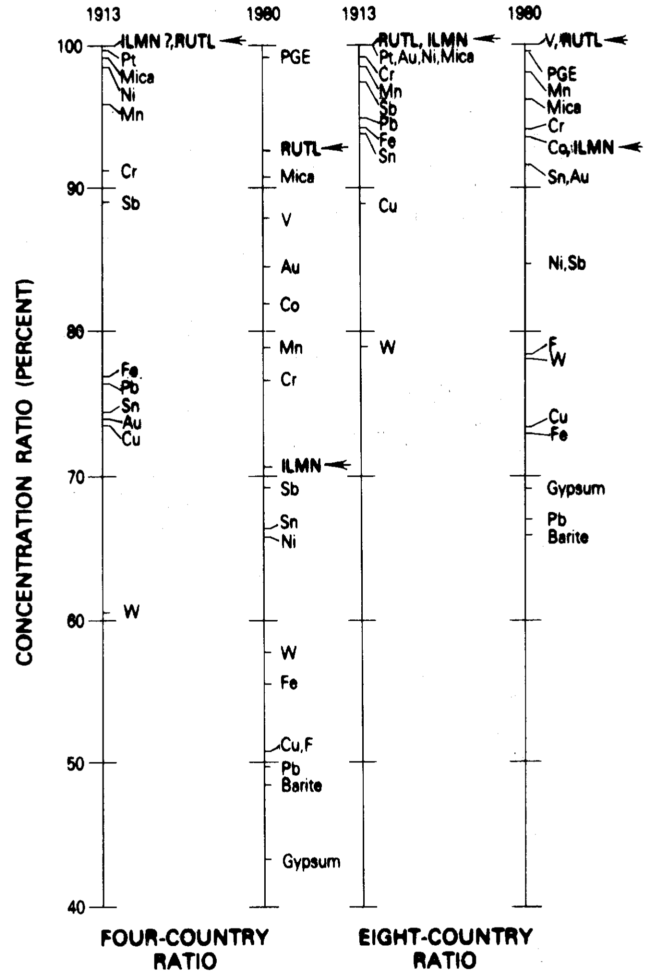


Figure 9.—Concentration ratios for selected nonfuel mineral commodity production in 1913 and 1980. The ratios are percent of total world production for the indicated commodities, designated by chemical-element symbols (PGE for platinum-group elements), for the four or eight countries with the largest reported production of the commodity in 1913 and 1980. (Sources of data: U.S. Geological Survey, 1921; U.S. Bureau of Mines, 1982.)

Surface mining, which accounts for 96 percent of the reported cumulative ilmenite production and 100 percent of the reported cumulative rutile production, is by far the most common method of recovering ore from the world's major

TABLE 7.—*Estimated annual (1985) and cumulative (1925-85) production of ilmenite and rutile, by economic class of country*

[Figures are calculated from reported production figures (U.S. Bureau of Mines, 1926-87; British Geological Survey, 1987) and are in thousand metric tons; figures may not add to totals shown due to rounding. Figures in parentheses denote percentage of world total. N.r.=None reported]

Economic class[1]	Ilmenite[2]		Rutile	
	Annual production	Cumulative production	Annual production	Cumulative production
Low-income	425 (7)	11,430 (9)	97 (24)	760 (8)
Lower middle-income	N.r.	591 (0)	N.r.	24 (0)
Upper middle-income	935 (17)	8,515 (7)	63 (15)	459 (5)
Industrial market	3,860 (68)	100,880 (80)	242 (59)	8,694 (86)
East European nonmarket	451 (8)	4,552 (4)	10 (2)	140 (1)
Total	5,671 (100)	125,968 (100)	412 (100)	10,077 (100)

[1] Based principally on GNP per capita and, in some instances, other distinguishing economic characteristics (World Bank, 1985, p. 174-175 and 243). Countries where major ilmenite and rutile deposits or districts occur are shown in figures 4 and 5. Also includes minor production for the following countries not included in the inventory (in order of importance): ilmenite—Spain, Senegal, Egypt, Gambia, Portugal (current producer), and Thailand; rutile—Cameroon, Egypt, and Senegal. See table 6.

[2] Includes equivalent titania slag, leucoxene, and perovskite.

titanium deposits (table 5). The remaining 4 percent of ilmenite production has come from the Otanmaki deposit in Finland which is mined by underground methods. An additional but unreported quantity has come from the Soviet Union's Kopansk deposit, which is also mined by underground methods.

Present and probable future (2020) production status of the world's major ilmenite and rutile deposits is shown in figures 10 and 11. Several current major producers (Tellnes, Norway; Richards Bay, South Africa; Lac Tio, Canada; Gusevogorsk, Soviet Union, and others) will probably continue to be substantial suppliers through 2020. In addition, other deposits which are minor producers or those which have not yet been developed (Salitre, Brazil; Piampaludo, Italy; Tamatave district, Madagascar, and others), may by then be major producers. However, other major deposits currently in production (North Stradbroke Island, Capel, and Eneabba, Australia; and Trail Ridge and Green Cove Springs, United States, and others) will likely be exhausted by 2020. It is also likely that by 2020 there will be several new major deposits in production that have yet to be discovered.

The relative contribution to world production by various countries is likely to change by 2020. China, the Soviet Union, and India may emerge with Canada, South Africa, and Norway as leaders in world production of ilmenite, with Australia and the United States probably declining in importance. In regard to rutile, India and Italy may emerge with South Africa and probably Sierra Leone as leaders in world production, while Australia and the United States become less important. It is possible, depending on the successful exploitation of their large reserves of anatase, that by 2020 the rutile market may be dominated by Brazil. These forecasts do not take account of the possible discovery of new deposits, of possible affects of technological advances on the economics of mining known deposits, or of supply and demand changes.

TABLE 8.—*Export of titanium products by country in 1984*

[Source: U.S. Bureau of Mines, 1987; British Geological Survey 1986-87. Figures are in metric tons; figures may not add to totals shown due to rounding. Figures in parentheses are percent of column totals. Countries with major ilmenite or rutile deposits in the International Strategic Minerals Inventory are noted with an asterisk (*)]

Country[1]	Ilmenite[2]	Rutile	Titania slag	Titanium dioxide	Metal[3]
* Australia	1,203,945 (53)	191,509 (56)	N.r.	26,000 (7)	N.r.
Belgium-Luxembourg	1 (0)	N.r.	N.r.	35,053 (9)	184 (1)
* Brazil	N.r.	N.r.	N.r.	.45 (0)	3 (0)
* Canada	N.r.	N.r.	650,000 (80)	23,779 (6)	363 (2)
* China	N.r.	N.r.	N.r.	2,045 (1)	133 (1)
Czechoslovakia	N.r.	N.r.	N.r.	2,432 (1)	N.r.
* Finland	N.r.	N.r.	N.r.	39,500 (11)	N.r.
France	95 (0)	N.r.	N.r.	22,488 (6)	N.r.
Germany (FRG)	8,338 (0)	N.r.	N.r.	59,954 (16)	2,316 (14)
Hong Kong	N.r.	N.r.	N.r.	1,926 (1)	N.r.
* India	[4]10,000 (0)	N.r.	N.r.	[4]100 (0)	N.r.
* Italy	990 (0)	N.r.	N.r.	1,931 (1)	200 (1)
Japan	N.r.	N.r.	N.r.	17,222 (5)	6,710 (40)
Korea	54 (0)	N.r.	N.r.	1,796 (0)	N.r.
* Malaysia	224,152 (10)	N.r.	N.r.	57 (0)	16 (0)
Netherlands	47,659 (2)	N.r.	N.r.	4,230 (1)	99 (1)
* Norway	599,214 (27)	N.r.	N.r.	2,474 (1)	N.r
* Sierra Leone	N.r.	91,300 (27)	N.r.	N.r.	N.r
* South Africa	48,180 (2)	56,000 (16)	[4]160,000 (20)	85 (0)	N.r
* Soviet Union	N.r.	N.r.	N.r.	655 (0)	N.r
Spain	18,202 (1)	N.r.	N.r.	N.r.	1 (0)
* Sri Lanka	96,066 (4)	N.r.	N.r.	N.r.	N.r
Taiwan	N.r.	N.r.	N.r.	57 (0)	N.r
* United Kingdom	27 (0)	N.r.	N.r.	15,411 (4)	N.r
* United States	3,454 (0)	4,394 (1)	N.r.	98,200 (26)	6,652 (40)
Yugoslavia	N.r.	N.r.	N.r.	15,979 (4)	N.r
Total	2,260,377 (100)	343,201 (100)	810,000 (100)	371,374.45 (100)	16,690 (100)

[1] Countries involved in re-export of commodities are not included.

[2] May include leucoxene (Australia, United States).

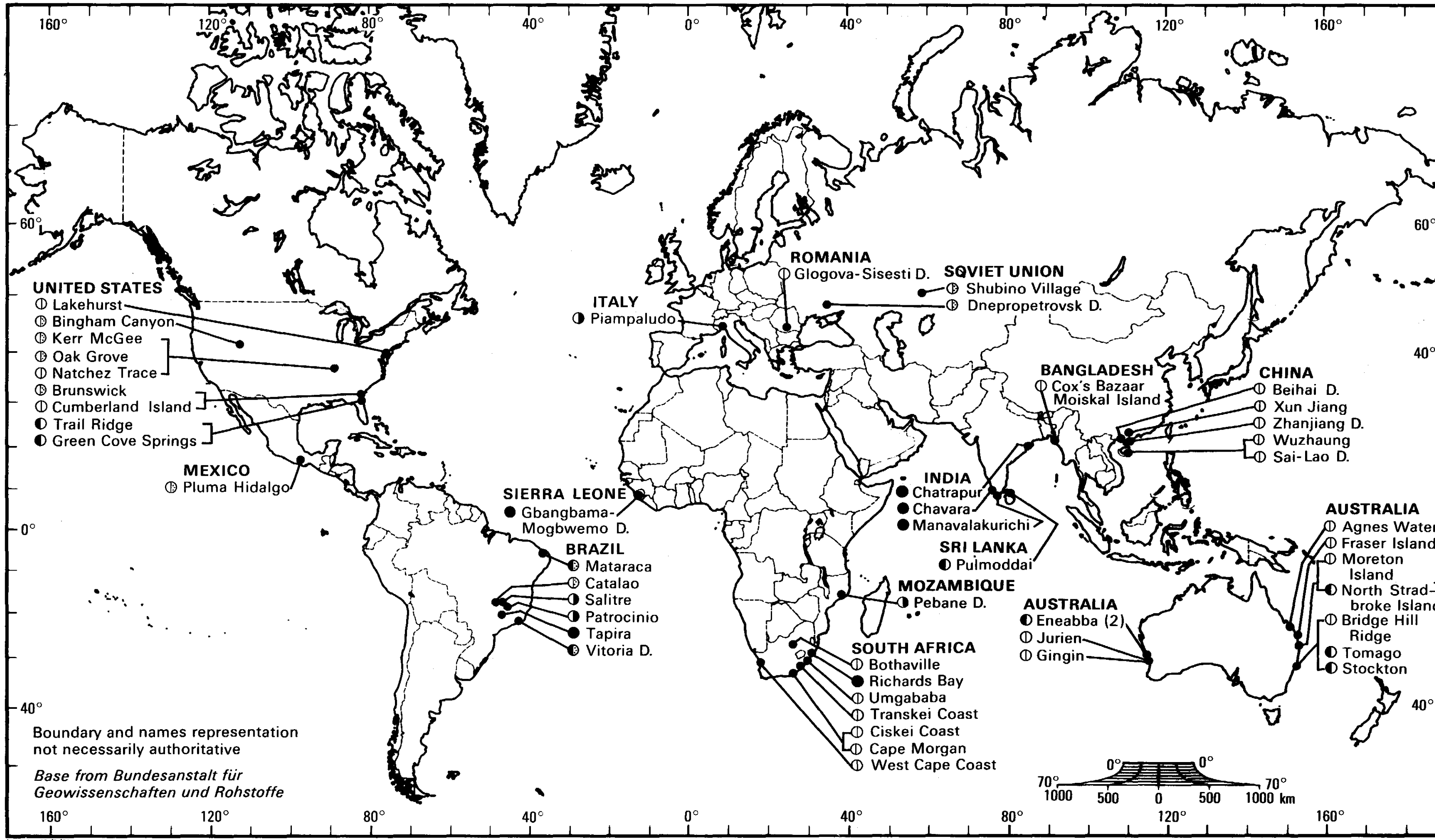
[3] Includes titanium metal sponge and ingots, and metal contained in alloys.

[4] Estimate.

TITANIUM EXPORTS

The world situation in regard to the current (1984) export of various titanium commmodities is shown in table 8 and figure 12. Only a few countries export significant amounts of titanium raw materials (ilmenite, titania slag, and rutile), because several of the producing countries consume most or all of their own production.

Australia and Norway are the major exporters of raw ilmenite concentrate. Canada and South

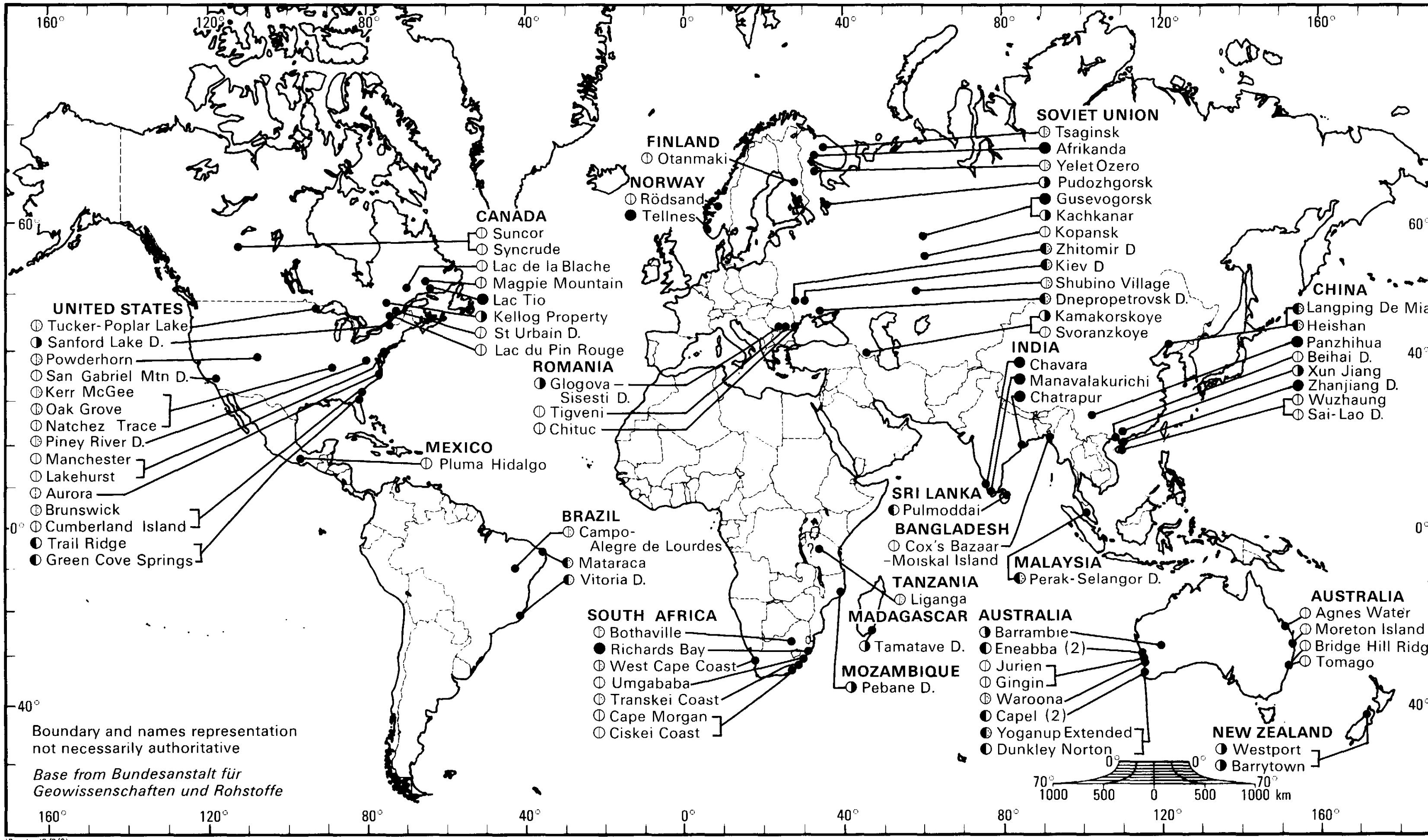


Current Significant Producer* — probably significant in 2020 ●
— probably insignificant in 2020 ◐
— insufficient information

Current nonsignificant producer — probably significant in 2020 ◑
— probably insignificant in 2020
— insufficient information

* > 1 000 metric tons per year D. District

Figure 11.—Major rutile deposits and districts, their present production status, and their probable production status in 2020. Numbers in parentheses indicate the number of records (deposits and districts) for each location. Location names are from the tables in Part II.



Current Significant Producer* — probably significant in 2020 ●
— probably insignificant in 2020 ◐
— insufficient information ◐

Current nonsignificant producer — probably significant in 2020 ◑
— probably insignificant in 2020 ⦶
— insufficient information ⦶

* > 20 000 metric tons per year D. District

Figure 10.—Major ilmenite deposits and districts, their present production status, and their probable production status in 2020. Numbers in parentheses indicate the number of records (deposits and districts) for each location. Location names are from the tables in Part II.

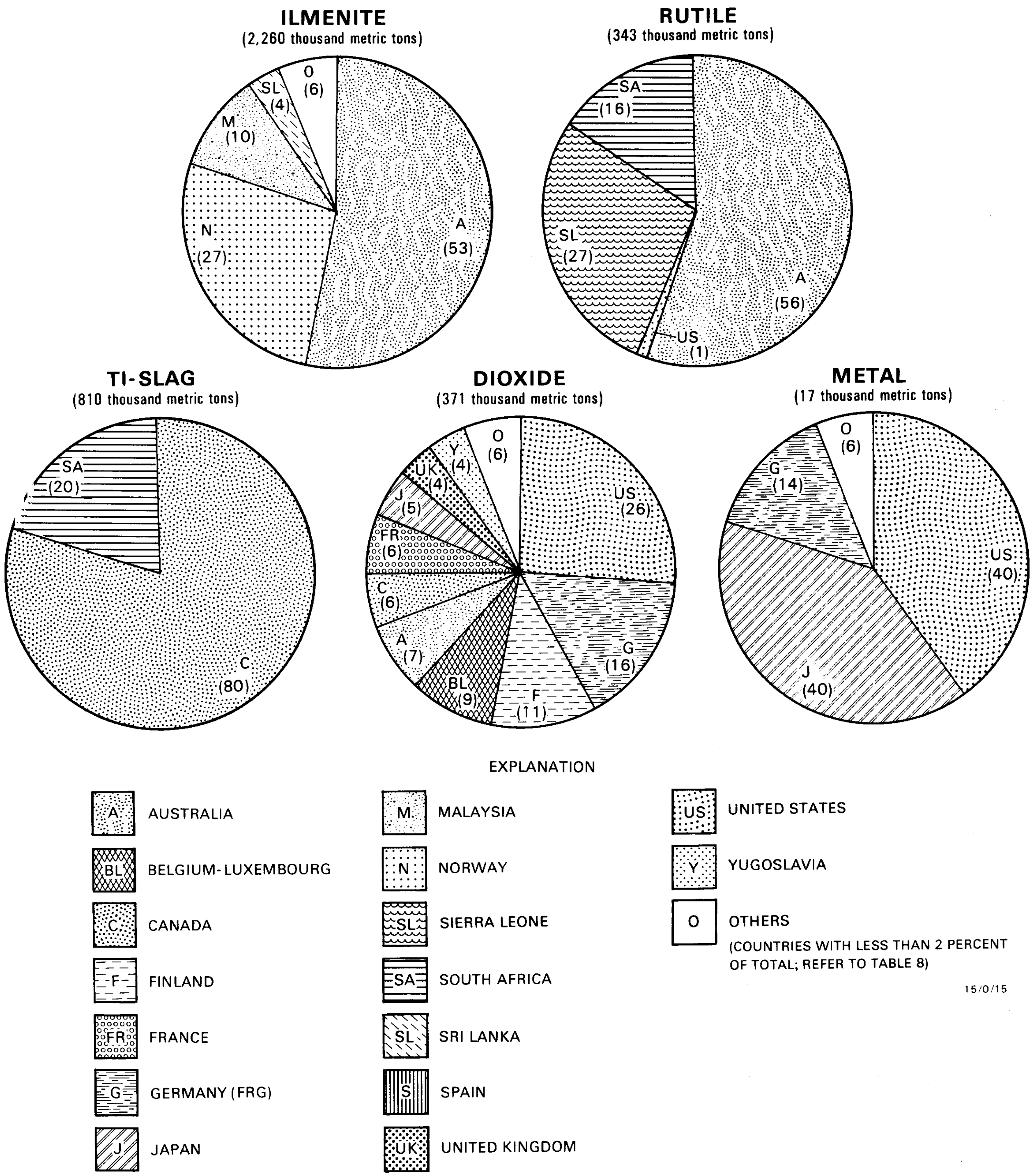


Figure 12.—Distribution of world exports of titanium products in 1984, by country (U.S. Bureau of Mines, 1987; British Geological Survey, 1986–87. Countries involved in re-export of commodities are not included. Ilmenite may include leucoxene (Australia, United States). Metal includes titanium metal sponge and ingots, and metal contained in alloys. Numbers in parentheses are percentages of the respective products exported by each country.

Africa upgrade their ilmenite to high-titanium-content products before export. These four countries account for most of the world's exported ilmenite and titania slag. Only four countries—Australia, South Africa, Sierra Leone, and the United States—export rutile. Of these, Australia is the most significant, accounting for nearly 60 percent of the total rutile exported.

Twenty-two countries (table 9) are involved in the manufacture and export of titanium dioxide. Two other countries, Mexico and Poland (not listed in table 9), produce titanium dioxide for their own domestic markets. Only eight of these countries (Australia, Brazil, Canada, China, India, South Africa, Soviet Union, and the United States) are producers of titanium raw materials; the rest rely solely on imported supplies. The leading exporters of titanium dioxide are the United States and West Germany, followed by Belgium-Luxembourg and Finland. Only five countries—China, Japan, the Soviet Union, United Kingdom, and United States—manufacture and export titanium sponge metal. Of these five countries, the United States and Japan, relying on imported raw materials, account for over 80 percent of world titanium sponge metal exports. The United Kingdom also relies on imported raw materials. The Soviet Union and China rely on locally supplied materials to produce titanium sponge metals for export. Other countries listed in table 9 manufacture titanium metal ingots and alloys from imported titanium metal sponge and export these products.

CONCLUSIONS

Titanium metal is strong, lightweight, corrosion resistant, and has a high melting point. It is, therefore, important to many industries, particularly the aerospace industry. There are no satisfactory substitutes for titanium, especially titanium metal. These factors, and the fact that the world's titanium resources are located in relatively few countries, lead those countries dependent on imported supplies to consider titanium a strategic commodity. The minerals currently being mined as sources of titanium are ilmenite, rutile, leucoxene, and titanomagnetite. Leucoxene and titanomagnetite are considered together with ilmenite in this report. Anatase resources are likely to be important in the future. Ninety-five percent of the world's titanium-ore production goes toward making titanium dioxide which is primarily used as a paint pigment. Most of the remaining ore production is used for making titanium metal, with all Western titanium metal producers using rutile as the raw material.

China and the Soviet Union have the largest share of the world's well-defined, minable resources of ilmenite with about 25 percent each. Canada, Norway, India, and South Africa also have very large ilmenite resources. The world's well-defined, minable resources of rutile are divided primarily between Australia, Italy, South Africa, and India. However, by including its large anatase resources with rutile, Brazil would have more than 75 percent of the world's resources.

Australia and Canada are the major producers of ilmenite, each with over 20 percent of the world total. South Africa, Norway, and the Soviet Union account for another 34 percent. Australia is the dominant producer of rutile, accounting for 52 percent of the world total. Sierra Leone and South Africa account for 35 percent of world rutile production.

The inventory's ilmenite and rutile resource data, together with projected production levels, suggest that world production from various countries could be substantially different by the year 2020. By then, Canada, South Africa, Norway, China, the Soviet Union, India, and Madagascar may be the leading ilmenite producers, and South Africa, Sierra Leone, and possibly India and Italy the leading rutile producers. The rutile market at that time could be dominated by Brazil if that country is successful in developing its large resources of anatase. However, because of the dynamic nature of mineral resources, this scenario could change to take account of new discoveries and (or) the effects of technological changes on supply and demand of TiO_2.

PART II—SELECTED INVENTORY INFORMATION FOR TITANIUM DEPOSITS AND DISTRICTS

Tables 9 and 10 contain information from the International Strategic Minerals Inventory record forms for titanium deposits and districts. Only selected items of information about the location and geology (table 9) and mineral production and resources (table 10) 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.

Abbreviations used throughout this table include:

---, Not reported on the ISMI record form
Fm, formation
Ma, Million years
asl, Above sea level

Age abbreviations and prefixes:

Cenozoic ....CEN	Miocene ....MIO	Carboniferous ....CARB	Late L
Quaternary.......QUAT	Oligocene ....OLIGO	Ordovician ....ORD	Middle ....M
Holocene.........HOLO	Eocene ....EO	Cambrian........CAMB	Early ....E
Pleistocene.......PLEIS	Cretaceous ....CRET	Precambrian .....PREC	
Tertiary ....TERT	Paleozoic ....PAL	Proterozoic.......PROT	
Pliocene ....PLIO	Permian ....PERM	Archean ....ARCH	

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
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	LTERT-QUAT
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°50′S., 151°41′E.	----- do. --------------------	Sand; PLEIS	PLEIS
WEST COAST				
Barrambie deposit	27°25′S., 119°07′E.	Magmatic, basic, stratiform, massive.	Anorthosite; Barrambie Intrusion; ARCH.	ARCH
Capel (AMC) deposit	33°33′S., 115°33′E.	Placer, marine	Sand; Bassendean Sand; EPLEIS.	PLEIS
Capel North deposit	33°31′S., 115°35′E.	----- do. --------------------	----- do. ------------------	----- do. ------------------
Dunkley/Norton deposit.	33°31′S., 115°33′E.	----- do. --------------------	----- do. ------------------	----- do. ------------------
Eneabba (Allied) deposit.	29°54′S., 115°16′E.	----- do. --------------------	Sand; LTERT-PLEIS	LTERT-PLEIS

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

Amphibole	AMPB	Garnet	GRNT	Mica	MICA	Rutile	RUTL
Anatase	ANTS	Goethite	GTHT	Molybdenite	MLBD	Sillimanite	SLMN
Apatite	APTT	Gold	GOLD	Monazite	MNZT	Staurolite	STRL
Biotite	BOTT	Heavy minerals	HM	Olivine	OLVN	Sulfides	SLPD
Bornite	BRNT	Hematite	HMTT	Perovskite	PRVK	Titanomagnetite	Ti-MGNT
Cassiterite	CSTR	Hornblende	HBLD	Plagioclase	PLGC	Tourmaline	TRML
Chalcocite	CLCC	Ilmenite	ILMN	Pyrite	PYRT	Ulvospinel	ULVP
Chalcopyrite	CLCP	Kyanite	KYNT	Pyroxene	PRXN	Zircon	ZRCN
Chlorite	CLRT	Leucoxene	LCXN	Pyrrhotite	PYTT		
Clay	CLAY	Magnetite	MGNT	Quartz	QRTZ		
Feldspar	FLDP	Martite	MRTT	Rare-earth-elements	REE		

Tectonic setting	Local environment	Principal mineral assemblages	Comments	References
		AUSTRALIA—Continued		
Basin	Dune, beach	ILMN, RUTL, ZRCN, MNZT; QRTZ.	Dune deposits. Avg grade: 0.18 percent RUTL, 1.36 percent ILMN.	Mineral Deposits Ltd. (1978).
----- do. ---------	----- do. -----------	RUTL, ILMN, ZRCN, MNZT; QRTZ.	Dune deposits. Avg grade: 0.15 to 0.2 percent RUTL.	Australian Business (1984); Coffey and Hollingsworth Pty. Ltd. (1973).
----- do. ---------	----- do. -----------	RUTL, ZRCN, ILMN; QRTZ.	Dune and beach deposits.	Australian Government (1976).
----- do. ---------	----- do. -----------	RUTL, ZRCN, ILMN; QRTZ.	Dune and beach deposits. Avg grade: 0.2 percent RUTL, 0.4 percent ILMN.	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 RUTL, 0.6 percent ILMN, and 0.3 percent ZRCN.	Australian Business (1984); Consolidated Rutile Limited (1985).
----- do. ---------	Dune, beach	RUTL, ZRCN, ILMN, MNZT; QRTZ.	Deposit is 2 km inland and has two distinct ore bodies: western dunes and eastern beach. Avg grade: 0.16 percent RUTL.	Mineral Deposits Ltd. (1977).
----- do. ---------	----- do. -----------	ZRCN, RUTL, ILMN, MNZT; QRTZ.	Ore occurs as lens-shaped bodies over distance of 15 km. Avg grade: 0.7 percent ZRCN, 0.5 percent RUTL, 0.2 percent ILMN.	Crofts and Associates Pty. Ltd. (1983).
PREC Shield	Intrusive complex.	MRTT, Ti-MGNT, ILMN, LCXN; GTHT, CLAY.	Three main zones (up to 25 m wide) of banded Ti-MGNT. Deeply weathered (to 60 m), intense martitization of MGNT.	Ward (1975); Ferrovanadium Corporation NL (1980-83).
Basin	Dune, beach	ILMN, ZRCN, LCXN; QRTZ.	Sequence of 10 heavy-mineral beach and dune sand units; forms part of Capel Shoreline.	Welch and others (1975); Australian Business (1984).
----- do. ---------	Dune	ILMN, ZRCN, LCXN, MNZT; QRTZ.	Part of Bassendean dune system along Capel Shoreline. Deposit is 6 km long and up 12 m thick.	Australian Business (1984); Baxter (1977).
----- do. ---------	Dune, beach	ILMN, ZRCN, LCXN; QRTZ.	Dune and beach deposits in Capel Shoreline; strandline 3 to 6 m and 4.8 to 6 m asl.	Baxter (1977).
----- 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 (1984).

TABLE 9.—*Selected geologic and location information from*

Site name	Latitude longitude	Deposit type	Host rock	Age of mineralization
		AUSTRALIA—Continued		
Eneabba (AMC) deposit.	29°47′S., 115°19′E.	Placer, marine	Sand; LTERT-PLEIS	LTERT-PLEIS
Gingin deposit	31°17′S., 115°52′E.	----- do. --------------------	Clayey sand; QUAT	QUAT
Jurien deposit	30°19′S., 115°10′E.	----- do. --------------------	Sand; QUAT	----- do. ------------------
Waroona deposit	32°50′S., 115°55′E.	----- do. --------------------	Sand; PLEIS	PLEIS
Yoganup Extended deposit.	33°25′S., 115°41′E.	----- do. --------------------	Sand, clay; Yoganup fm; EPLEIS.	LTERT?-EPLEIS
		BANGLADESH		
Cox's Bazaar-Moiskal Island deposit.	21°20′N., 91°55′E.	Placer, marine	Sand; QUAT	QUAT
		BRAZIL		
Campo Alegre de Lourdes deposit.	11°S., 43°W.	Magmatic, basic, stratiform, massive.	Gabbro; PREC	PREC?
Catalao deposit	8°12′S., 47°54′W.	Laterite	Laterite (after pyroxenite); LCRET.	CRET-HOLO
Mataraca deposit	6°30′S., 35°00′W.	Placer, marine	Sand; CEN	CEN
Patrocinio deposit	18°55′S., 46°50′W.	Laterite	Laterite (after pyroxenite); LCRET.	CRET-HOLO
Salitre deposit	18°40′S., 46°00′W.	----- do. --------------------	----- do. ------------------	CRET (82 Ma)-HOLO
Tapira deposit	19°52′S., 46°50′W.	----- do. --------------------	----- do. ------------------	CRET (70 Ma)-HOLO
Vitoria district	18–22°S., 40–42°W.	Placer, marine	Sand; QUAT	QUAT

ISMI records for titanium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	References
		AUSTRALIA—Continued		
Basin	Beach, dune	ILMN, ZRCN, RUTL, LCXN, KYNT, MNZT.	Beach and dune deposits at base of Gingin Scarp.	Baxter (1977); Australian Business (1984).
----- do. -------------	Beach, lagoon?	ILMN, ZRCN, RUTL; QRTZ.	Orebody is up to 60 percent HM and 12 to 30 percent clay. Occurs on Gingin Shoreline for 5 km and is up to 250 m wide.	Do.
----- do. -------------	Beach, dune	ILMN, RUTL, ZRCN, GRNT; QRTZ.	Five separate heavy-mineral lenses; three beach, two dune. Occurs along the Munbinea Shoreline.	Baxter (1977); TiO_2 Corporation (1985).
----- do. -------------	Dune	ILMN, ZRCN, LCXN; QRTZ.	Occurs along Waroona Shoreline in dune sands up to 9 m thick with up to 60 percent HM.	Baxter (1977).
----- do. -------------	Beach, dune	ILMN, ZRCN, LCXN, MNZT; QRTZ.	Beach and dune deposits in Yoganup Shoreline. Strandlines 43 to 46 m asl with ILMN having 57 percent TiO_2.	Baxter (1982); Australian Business (1984).
		BANGLADESH—Continued		
Basin	Beach, dune	ILMN, RUTL, LCXN, ZRCN, KYNT; QRTZ.	Only back dunes are economic. Deposits occur as lenses 1.5 to 7.5 m thick and 30 to 240 m long.	Howarth and others (1977).
		BRAZIL—Continued		
PREC shield	Intrusive into PREC succession.	ILMN, LCXN, HMTT, MGNT; PRXN, FLDP.	Ore occurs in massive bands in lens-shaped hills up to 100 m wide and 1 km long. Associated with oxidized zone of intrusion.	Beurlen and Cassedanne, (1981).
----- do. -------------	Explosive intrusion into PROT succession.	ANTS, LCXN, PRVK, ILMN, MGNT.	ANTS-rich (approx 90 percent TiO_2) mantle produced by tropical weathering of the pyroxenite in the alkaline complex.	Harben (1984); Beurlen and Cassedanne (1981).
Basin	Beach, dune	ILMN, ZRCN, RUTL, MNZT, GRNT; TRML, QRTZ.	Series of sand dunes lying parallel with coast stretching approx 20 km. Total HM: 5.6 percent.	Harben (1984).
Shield	Explosive intrusion into PROT succession.	ANTS, LCXN, PRVK, ILMN, MGNT.	As for Catalao deposit.	Gazeta Mercantil (1984); Harben (1984).
PREC shield	----- do. -----------	ANTS, LCXN, PRVK, ILMN, MGNT.	----- do. -----------------------------	Harben (1984).
----- do. -------------	----- do. -----------	ANTS, LCXN, PRVK, ILMN, MGNT.	As for Catalao deposit. Avg depth of weathering 60 m, max depth 200 m. Five major weathering zones:(1) sterile, (2) ANTS + MGNT, (3) ANTS + APTT, (4) APTT,(5) sterile.	Harben (1984); Cruz and others (1976); Herz (1976).
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 9.—*Selected geologic and location information from*

Site name	Latitude longitude	Deposit type	Host rock	Age of mineralization
		CANADA		
Kellogg Property deposit	49°49′N., 74°00′W.	Magmatic, basic, stratiform, massive.	Metapyroxenite, metagabbro; Dore Lake Complex; ARCH.	ARCH
Lac de la Blache deposit	50°04′N., 69°38′W.	----- do. --------------------	Anorthosite; PROT	PROT
Lac du Pin Rouge deposit	45°58′N., 74°03′W.	Magmatic, basic, massive/disseminated.	Gabbro, anorthosite; PROT.	----- do. ------------------
Lac Tio deposit	50°33′N., 63°25′W.	Magmatic, basic, irregular, massive.	Anorthosite; PROT	----- do. ------------------
Magpie Mountain deposit	51°23′N., 64°04′W.	Magmatic, basic, massive/disseminated.	Anorthosite, gabbro, granitic gneiss; PROT.	----- do. ------------------
St. Urbain district	47°32′N., 70°33′W.	Magmatic, basic, massive.	Anorthosite; PROT	----- do. ------------------
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. ------------------
		CHINA		
Beihai district	21°29′N., 109°06′E.	Placer, marine; placer, continental.	Sand; CEN	CEN
Heishan deposit	41°00′N., 118°00′E.	Magmatic	---	---
Langping De Miao deposit.	41°00′N., 118°00′E.	----- do. --------------------	---	---
Panzhihua deposit	26°33′N., 101°50′E.	----- do. --------------------	---	---
Sai-Lao district (Quoinghi).	19°15′N., 110°36′E.	Placer, marine	Sand; CEN	CEN
Wuzhaung deposit (Wanning).	18°43′N., 110°22′E.	----- do. --------------------	----- do. ------------------	----- do. ------------------
Xun Jiang deposit	23°30′N., 110°50′E.	Placer, continental	----- do. ------------------	----- do. ------------------

ISMI records for titanium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	References
		CANADA—Continued		
Archean (volcanic) greenstone belt.	Layered anorthosite gabbro sill.	Ti-V-MGNT, ILMN; PRXN, AMPB, FLDP.	MGNT-rich zones are discontinuous layered magmatic segregations. Three main zones each 1200 m long, 75 to 90 m thick.	Rose (1969, 1973).
Grenville Orogenic Belt.	Anorthosite intrusion.	MGNT, ILMN, ULVP; PRXN, FLDP.	Masses and lenses of MGNT and ILMN. MGNT may contain ILMN and ULVP inclusions. Four deposits in a 10-km line.	Waddington (1960).
----- do. -------------	Gabbro and anorthosite intrusions.	ILMN, HMTT, Ti-MGNT; PRXN, FLDP.	Lenses of ILMN-HMTT and disseminated Ti-MGNT.	Rose (1969); Gross (1967).
----- do. -------------	Anorthosite intrusions.	ILMN, HMTT, MGNT; PLGC, PRXN, BOTT.	Occurs mainly as a large sheet or lense within the anorthosite.	Rose (1969); Kennecott Corporation (1959–82).
----- do. -------------	----- do. -----------	MGNT, ILMN; PLGC	Four deposits of massive MGNT with exsolved ILMN occur as tabular, steeply dipping bodies up to 300 m wide.	Vallée and Raby (1971); Rose (1969).
----- do. -------------	Anorthosite intrusion.	ILMN, HMTT, RUTL; FLDP, PRXN.	15 to 20 percent HMTT as exsolved blades in ILMN. Up to 10 percent RUTL in some deposits. At least six individual deposits.	Rose (1969); Gross (1967).
Alberta Basin	Coastal marine	ILMN, ZRCN, LCXN, RUTL; QRTZ.	In Athabasca oil sands, HM range from 0.24 to 2.29 percent. Bitumen content 0 to 18 percent.	Kramers and Brown (1976); Trevoy and others (1978).
----- do. -------------	----- do. -----------	ILMN, ZRCN, LCXN, RUTL; QRTZ.	----- do. ------------------------------	Do.
		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 over a width of 2 km. Avg 1.3 percent HM.	U.S. Bureau of Mines (1982).
----- do. -------------	Magmatic intrusion.	Ti-MGNT?	Deposit is in Ti-MGNT iron ore containing 0.2 to 0.3 percent V.	Furukawa (1984).
----- do. -------------	----- do. -----------	Ti-MGNT?	----- do. ------------------------------	Do.
----- do. -------------	Magmatic intrusion.	MGNT, ILMN	Ore is V-Ti-MGNT containing 8 to 10 percent TiO_2. Also present are Cr, Ni, Co, Mo, and others.	U.S. Bureau of Mines (1982); Furukawa (1984).
----- do. -------------	Coastal beach	ILMN, ZRCN, MNZT, RUTL, ANTS; QRTZ.	Several parallel strands in some places. Typically 5 m deep, 2 to 3 percent HM.	U.S. Bureau of Mines (1982).
----- do. -------------	----- do. -----------	ILMN, ZRCN, MNZT, RUTL, ANTS; QRTZ.	Typically 8 to 10 m deep but may be up to 30 m.	Do.
----- do. -------------	River plain (100 m asl).	ILMN; minor RUTL, ZRCN, MNZT; QRTZ.	Typically 5 m deep, 5 to 7 percent HM.	Do.

TABLE 9.—*Selected geologic and location information from*

Site name	Latitude longitude	Deposit type	Host rock	Age of mineralization
		CHINA—Continued		
Zhanjiang district	21°12′N., 110°28′E.	Placer, marine; placer, continental.	Sand; CEN	CEN
		FINLAND		
Otanmaki deposit	64°10′N., 27°10′E.	Magmatic, basic, strati-form, massive.	Hornblende gabbro; PROT.	PROT (2,050 Ma)
		INDIA		
Chatrapur deposit	19°26′N., 85°02′E.	Placer, marine	Sand; QUAT	QUAT
Chavara deposit	9°10′N., 76°30′E.	----- do. --------------------	----- do. ------------------	----- do. ------------------
Manavalakurichi deposit	8°12′N., 77°20′E.	----- do. --------------------	----- do. ------------------	----- do. ------------------
		ITALY		
Piampaludo deposit	44°28′N., 3°52′E.	Metamorphic	Eclogite after ferrogabbro.	---
		MADAGASCAR		
Tamatave district	18°S., 50°E.	Placer, marine	Sand; CEN	CEN
		MALAYSIA		
Perak-Selangor district	3–5°N., 101–102°E.	Placer, continental	Sand, clay, gravel; QUAT.	QUAT
		MEXICO		
Pluma Hidalgo deposit	15°55′N., 96°25′W.	Magmatic, acid, irregular, massive.	Anorthosite; PAL	PAL
		MOZAMBIQUE		
Pebane district	17°S., 38°E.	Placer, marine	Sand, QUAT	QUAT

ISMI records for titanium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	References
		CHINA—Continued		
Basin	Beach and river sands on coastal plain.	ILMN, ZRCN, MNZT, RUTL; QRTZ.	Region contains several hundred kilometers of coastline with HM-bearing sands. Five processing plants in region. Sands avg 2 to 3 percent Ti minerals.	U.S. Bureau of Mines (1982).
		FINLAND—Continued		
PREC shield	Magmatic intrusion.	MGNT, ILMN; CLRT, MLBD, PLGC.	Ore-bearing zone 2 km×500 m. Contains several hundred ore lenses 20 to 200 m long, 5 to 30 m wide. Several ore types; highest grade 35 to 40 percent MGNT, 28 to 30 percent ILMN.	Lindholm and Anttonen (1980); Zitzmann (1977-78).
		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 elevation 17 m asl. Approx 20 percent HM, 80 percent QRTZ.	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 68 percent ILMN, 7 percent RUTL, 2 percent LCXN.	Adams (1984); Lynd and Lefond (1975).
----- do. -------------	----- do. -----------	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.	---
		ITALY—Continued		
---	Eclogite facies metamorphism.	RUTL, GRNT, ILMN, PYRT; PRXN, FLDP.	Eclogite averages 3 to 4 percent RUTL, 30 percent GRNT, minor ILMN.	Watson (1980); Adams (1984).
		MADAGASCAR—Continued		
Basin	Coastal	ILMN; QRTZ?	No details available.	Mining Magazine (1986).
		MALAYSIA—Continued		
Basin	Alluvial	ILMN, CSTR, ZRCN, MNZT.	ILMN produced as a byproduct of tin. District includes two provinces. Main area is Kinta Valley.	Adams (1984); Cheang (1984).
		MEXICO—Continued		
---	Magmatic intrusion.	ILMN, RUTL, LCXN; APTT, CLRT.	Elongated, irregular lenses, avg 1.8 m thick, and are parallel with gneissic structure. Grades are extremely high (20 percent RUTL is common).	Engineering and Mining Journal (1984); Paulson (1964).
		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); United Nations Economic Commission for Africa (1981).

TABLE 9.—*Selected geologic and location information from*

Site name	Latitude longitude	Deposit type	Host rock	Age of mineralization
		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. ------------------
		NORWAY		
Rödsand deposit	62°48′N., 8°10′E.	Magmatic, acid, stratiform, massive.	Amphibolite in granitic gneiss; Rodsand Group; PROT.	PROT (1,600–1,900 Ma).
Tellnes deposit	58°19′N., 16°26′E.	Magmatic, basic, stratiform, disseminated.	Norite; Ergersund Anorthosite Complex; PROT.	PROT (950 Ma)
		ROMANIA		
Chituc deposit	45°00′N., 29°38′E.	Placer, marine	Sand; Caraorman Fm, Letea Fm; HOLO.	HOLO
Glogova-Sisesti district	44°55′N., 22°58′E.	----- do. --------------------	Sand; PLIO–PLEIS	PLIO–PLEIS
Tigveni deposit	45°10′N., 24°35′E.	Placer, marine	Sand; PLIO–PLEIS	PLIO–PLEIS
		SIERRA LEONE		
Gbangbama-Mogbwemo district.	7°47′N., 12°18′W.	Placer, continental	Sand, clay; Bullom Series; TERT–QUAT.	TERT–QUAT

ISMI records for titanium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	References
		NEW ZEALAND—Continued		
Basin	Coastal beach	ILMN, GRNT, ZRCN, MGNT, RUTL, MNZT; QRTZ; FLDP.	Bulk of deposit is in fringing shoreline. It is 5.2 m thick, with 10 percent ILMN, and contains a band of pebbles and gravel. Additional resources in PLEIS strandlines further inland (Avg 5 percent ILMN).	McPherson (1978); Ward (1972).
----- do. -------------	----- do. -----------	ILMN, GRNT, ZRCN, MGNT, RUTL, MNZT; QRTZ; FLDP.	----- do. -----------------------------	Do.
		NORWAY—Continued		
PREC shield	Magmatic intrusion.	MGNT, ILMN, HMTT; PYRT, PYTT, CLCP; AMPB, PLGC.	Ore occurs as conformable lenses in amphibolite layers in granitic gneisses. ILMN contains varying proportions of exsolved HMTT.	Zitzmann (1977–78); Vokes (1979).
----- do. -------------	----- do. -----------	HMTT-ILMN, MGNT; PLGC, PRXN, BOTT.	Deposit consists of a single large body of ILMN-rich norite—2.7 km long, 400 m wide, 350 m deep. It contains 39 percent ILMN, 2 percent V-MGNT, and minor Cu/Ni SLPD.	Zitzmann (1977–78); Adams (1984); Dixon (1979).
		ROMANIA—Continued		
Basin	Coastal beach in delta area.	ILMN, MGNT, ZRCN, RUTL; QRTZ, GRNT.	HM sands fringe the inland margins of the sandbank in a zone 3.4 km long. Ore contains avg 5.5 percent ILMN, 0.3 percent RUTL.	U.S. Bureau of Mines (1982).
Sub-Carpathian Foredeep.	Ancient coastal beach.	ILMN, RUTL, GRNT, ZRCN; QRTZ, FLDP, MICA.	Three HM-bearing ancient beach formations: upper formation—sands, 15 m thick; mid formation—sands plus gravels, 12 m thick; base formation—fine sands, 15 m thick. Located on River Motru at 300 m asl.	Do.
----- do. -------------	----- do. -----------	ILMN, MGNT, HMTT; QRTZ, FLDP, MICA.	Located on banks of River Topolog at approx 400 m asl. Ore is in one of three HM-bearing formations as at Glogova-Sisesti district. ILMN comprises most of HM fraction.	U.S. Bureau of Mines (1982).
		SIERRA LEONE—Continued		
Basin	Alluvial deposits on coastal plain.	RUTL, ILMN, ZRCN; GRNT, QRTZ, CLAY.	Several isolated deposits in old drainage courses. The Mogbwemo deposit is the largest, richest and only one yet developed. RUTL grades highest in topsoil (avg 2.5 percent) and basal sands and gravels (up to 3.0 percent). Avg through section is 1.8 percent. RUTL is 80 percent of HM, ILMN 10 to 15 percent. Depth up to 25 m, avg 15 m.	Steinberger and Katz (1984); Adams (1984).

TABLE 9.—*Selected geologic and location information from*

Site name	Latitude longitude	Deposit type	Host rock	Age of mineralization
		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. ------------------
Richards Bay deposit	28°42′S., 32°10′E.	----- do. --------------------	Sand; QUAT	QUAT
Transkei Coast deposit	32°35′S., 28°31′E.	----- do. --------------------	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. ------------------
		SOVIET UNION		
Afrikanda deposit	67°15′N., 32°40′E.	Magmatic, alkalic	Pyroxenite, olivinite; CAMB-ORD.	CAMB-ORD
Dnepropetrovsk district	48°40′N., 34°22′E.	Placer, marine	Sand; Samotkan placer; TERT.	TERT
Gusevogorsk deposit	58°42′N., 59°36′E.	Magmatic, basic, strati-form, disseminat-ed/massive.	Pyroxenite; Gusevog-orsk Massif; CARB-PERM.	CARB-PERM
Kachkanar deposit	58°40′N., 59°29′E.	----- do. --------------------	Pyroxenite; Kachkanar Massif; CARB-PERM.	----- do. ------------------
Kamakorskoye deposit	39°02′N., 46°20′E.	Magmatic, basic, strati-form, disseminated.	Pyroxenite; LEO	LEO
Kiev district	---	Placer, continental?	Sand; CEN	CEN

ISMI records for titanium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	References
		SOUTH AFRICA—Continued		
Basin	Coastal beach	ILMN, HMTT, RUTL, LCXN, MGNT, ZRCN; QRTZ, GRNT.	Ore in consolidated-laminated sandstone. Deposits occur in a zone 16 km long and 12 km 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 approx 5 km. Ore in nonlayered aeolian dunes.	Do.
----- do. -------------	----- do. -----------	ILMN, RUTL, MGNT, ZRCN, LCXN; QRTZ, CLAY.	Consists of nonlayered aeolian dunes. Strike length is approx 6 km. Very high clay content.	Company reports (proprietary).
----- do. -------------	Coastal beach and dunes.	ILMN, LCXN, RUTL, ZRCN, MGNT; QRTZ, GRNT.	Ore is in nonlayered HOLO aeolian dunes and in well-layered PLEIS beach sand (1 m of cover). Deposits occur over a length of 110 km.	Hammerbeck (1976).
----- do. -------------	Coastal sand dunes.	ILMN, RUTL, ZRCN, MGNT; QRTZ.	Deposit is in layered dunes behind the beach and extends over 17 km.	Do.
----- do. -------------	----- do. -----------	ILMN, RUTL, ZRCN, MGNT; QRTZ.	Nonlayered aeolian dunes over 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 a 20-km-wide coastal strip.	Hammerbeck (1976).
		SOVIET UNION—Continued		
Geosyncline	Magmatic intrusion.	PRVK, Ti-MGNT; OLVN; PRXN.	Deposit is a large pipe-like body of disseminated PRVK and Ti-MGNT within pyroxenite, and has been traced to a depth of 400 m. Ore contains 8 to 18 percent TiO_2 (avg 9.6 percent), and 11 to 18 percent Fe (avg 13.5 percent).	Zitzmann (1977–78); U. S. Bureau of Mines (1982).
Basin	Coastal beach	ILMN, RUTL, LCXN, ANTS, ZRCN; QRTZ, CLAY.	Deposit attains a thickness of tens of meters, a width up to several kilometers and length of tens of kilometers. Occurs as layers or lenses.	U.S. Bureau of Mines (1982); Borisenko (1977a, b); Coope (1982).
Geosyncline	Magmatic intrusion into geosynclinal succession.	Ti-MGNT, ILMN, HMTT, PYRT; PRXN, AMPB.	Ti-MGNT ore contains 2 to 18 percent ILMN; occurs as disseminated ore, as schlieren, and veins of massive ores.	Zitzmann (1977–78); U.S. Bureau of Mines (1982).
----- do. -------------	----- do. -----------	Ti-MGNT, ILMN, HMTT, PYRT; PRXN, AMPB.	----- do. -----------------------------	Do.
Geosyncline?	Magmatic intrusion.	Ti-MGNT, ILMN; PRXN	Lode is well defined, but disseminated. Deposit is 1,200 m long, 30 to 90 m wide and 150 to 200 m thick. Contains 4 to 7 percent ILMN, and some copper minerals.	Zitzmann (1977–78); U.S. Bureau of Mines (1982).
Basin	Alluvial?	ILMN; QRTZ, FLDP, CLAY.	Principal mine is at Tarasovsk.	U.S. Bureau of Mines (1982).

TABLE 9.—*Selected geologic and location information from*

Site name	Latitude longitude	Deposit type	Host rock	Age of mineralization
		SOVIET UNION—Continued		
Kopansk deposit	55°06′N., 59°27′E.	Magmatic, basic, stratiform, massive/disseminated.	Gabbro; Kopansk Massif; PROT (1,300 Ma).	PROT (1,300 Ma)
Pudozhgorsk deposit	62°20′N., 35°55′E.	Magmatic, basic, stratiform, massive.	Gabbro, amphibolite; MPROT.	MPROT
Shubino Village deposit	51°N., 58°E.	Metamorphic	Eclogite	---
Svoranzkoye deposit	39°18′N., 46°11′E.	Magmatic, basic, stratiform, massive/disseminated.	Gabbro, olivinite; LEO	LEO
Tsaginsk deposit	67°45′N., 35°20′E.	Magmatic, stratiform, disseminated, massive.	Gabbro, anorthosite; Tsaginsk Massif; EPROT.	EPROT
Yelet Ozero deposit	66°N., 33°E.	Magmatic, stratiform, basic/alkalic, massive/disseminated.	Gabbro, pyroxenite, peridotite, amphibolite; MPROT-LPROT.	MPROT-LPROT
Zhitomir district	50°45′N., 28°30′E.	Placer, continental	Sand; Irsha placer; CRET-QUAT.	CRET-QUAT
		SRI LANKA		
Pulmoddai deposit	8°57′N., 80°57′E.	Placer, marine	Sand; QUAT	QUAT
		TANZANIA		
Liganga deposit	---	Magmatic, basic, stratiform, massive.	Ultrabasic rocks	---

ISMI records for titanium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	References
		SOVIET UNION—Continued		
PREC shield	Magmatic intrusion into PREC succession.	Ti-MGNT, MGNT, ILMN; PRXN, FLDP.	Vein-like segregations of massive ores (0.6–5.2 m thick) and zones of disseminated ores (avg 37 m thick). Ores are conformable with gabbro banding. Avg grade: massive ores, 11 percent TiO_2; disseminated ores, 6 percent TiO_2.	Zitzmann (1977–78); U.S. Bureau of Mines (1982).
----- do. -------------	Magmatic intrusion.	Ti-MGNT, ILMN, CLCP; PLGC, AMPB, PRXN.	Occurs in a segregational ore seam as schliers and disseminations. Ore is 7 to 24 m thick, 7.1 km long, and has a dip length of up to 400 m.	Do.
---	Eclogite facies metamorphism.	RUTL; GRNT, PRXN	Occurs in four isolated, conformable lenses of eclogite in a zone 60 m thick and averages approx 4.0 percent TiO_2.	Chesnokov (1960); U.S. Bureau of Mines (1982).
Geosyncline?	Magmatic intrusion	MGNT, Ti-MGNT, ILMN; PRXN, OLVN, FLDP.	Ore is in vein and lensoid bodies dipping 75 to 80°, and as disseminated ore. Avg analysis is 1.3 percent TiO_2 and 10 to 25 percent Fe.	Zitzmann (1977–78); U.S. Bureau of Mines (1982).
PREC shield	----- do. -----------	Ti-MGNT, ILMN	Occurs as rich disseminated ores (up to 40 percent Ti-MGNT) and as late magmatic veins. Avg grade of all ore: 36 percent Fe, 7 percent TiO_2, and 0.26 percent V_2O_5. Ores are restricted to inside contacts of the massif.	Yudin and Zak (1971); U.S. Bureau of Mines (1982).
----- do. -------------	----- do. -----------	ILMN, Ti-MGNT, MGNT; PRXN, AMPB, OLVN, PLGC.	Deposit primarily consists of late-stage magmatic ores as large layers of banded, coarsely disseminated ILMN-MGNT (8–26 percent TiO_2). Also occurs as disseminated Ti-MGNT ore (avg 2.5 percent TiO_2).	Do.
Basin	Alluvial	ILMN; QRTZ, FLDP, CLAY.	Deposits are ribbon-like placers in the lower coarse-grained horizons of fossil river valleys. Avg ILMN grade is 20 kg/m^3 but may reach 200 kg/m^3.	U.S. Bureau of Mines (1982); Borisenko (1977a, b).
		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 no overburden. Further resources are in backshore areas and an offshore strip hundreds of meters wide which replenishes excavated sand.	Clark (1983); Adams (1984).
		TANZANIA—Continued		
---	Magmatic intrusion.	MGNT, ILMN	Ore is found as Ti-V-MGNT and ILMN bands.	United Nations Economic Commission for Africa (1981).

TABLE 9.—*Selected geologic and location information from*

Site name	Latitude longitude	Deposit type	Host rock	Age of mineralization
		UNITED STATES		
Aurora deposit	34°14′N., 76°50′W.	Placer, marine	Sand; Minnesott sand; PLEIS.	PLEIS
Bingham Canyon deposit	40°31′N., 112°09′W.	Magmatic, hydrothermal.	Monzonite porphyry; OLIGO.	OLIGO (35 Ma)
Brunswick deposit	31°19′N., 81°28′W.	Placer, marine	Sand; Princess Anne Shoreline Complex; 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 Fm; MIO–PLIO.	MIO–PLIO
Manchester deposit	39°59′N., 74°21′W.	----- do. --------------------	----- do. ------------------	----- do. ------------------
Natchez Trace deposit	35°50′N., 88°12′W.	Placer, marine	Sand; McNairy Fm; LCRET.	LCRET
Oak Grove deposit	36°23′N., 88°10′W.	----- do. --------------------	----- do. ------------------	----- do. ------------------
Piney River district	37°42′N., 79°02′W.	Magmatic, basic, irregular/stratiform, massive.	Nelsonite, ferrodiorite; PROT.	PROT
Powderhorn deposit	38°15′N., 107°03′W.	Magmatic, alkalic, irregular/stratiform, massive/disseminated.	Pyroxenite; CAMB	CAMB
San Gabriel Mountain district.	34°23′N., 118°20′W.	Magmatic, basic, irregular/stratiform, massive.	Anorthosite; San Gabriel anorthosite.	---
Sanford Lake district	44°03′N., 74°03′W.	----- do. --------------------	Anorthosite, gabbro; Marcy anorthosite; PROT.	PROT

ISMI records for titanium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	References
		UNITED STATES—Continued		
Basin	Shoreline	ILMN, others?; QRTZ	Deposit is 6 m thick with 1.3 percent TiO_2. Ore is mostly ILMN having 45 percent TiO_2.	American Paint and Coatings Journal (1977).
---	Intrusion into PAL sediments.	CLCP, BRNT, CLCC, MLBD, RUTL, GOLD; FLDP, BOTT.	RUTL is disseminated throughout the Cu ore in this porphyry copper deposit.	Czamanske and others (1981).
Basin	Shoreline	ILMN, minor RUTL, LCXN, ZRCN, MNZT; QRTZ.	ILMN is approx 1.2 percent of the sand and contains 62 percent TiO_2.	Smith and others (1967).
----- do. ---------	----- do. -------------	ILMN, minor RUTL, LCXN, ZRCN, MNZT; QRTZ.	Avg grade 1.7 percent HM containing 45 percent ILMN, 7 percent RUTL, 3 percent LCXN, 13 percent ZRCN, and 1 percent MNZT.	Force, E.R., pers. commun.
----- do. ---------	----- do. -------------	ILMN, RUTL, LCXN, ZRCN, MNZT, QRTZ.	Consists of several strandlines, 16 m thick; grade ranges from 2 to 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 clay beds. ILMN has 62 percent TiO_2.	Wilcox (1971).
----- do. ---------	Deltaic	ILMN, ZRCN, LCXN, RUTL, KYNT; QRTZ.	Deposit occurs in a 7-m-thick medium-grained, quartz sandstone. Original grade 4 to 5 percent HM (80–85 percent ILMN, 3 percent RUTL).	Puffer and Cousminer (1982).
----- do. ---------	----- do. -------------	ILMN, ZRCN, RUTL, SLMN, KYNT, STRL; QRTZ.	Similar geology to Lakehurst deposit.	Markewicz (1969).
----- 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).
---	Igneous intrusion and dykes.	ILMN, APTT, minor MGNT, PYRT.	Two main deposits (Piney River and B.F. Camden anomaly) occur as cumulate-like enrichments or in dyke-like masses with APTT. Ore contains 13 to 20 percent ILMN.	Herz and Force (1987).
---	Alkalic intrusion	MGNT, PRVK, APTT; BOTT, PRXN.	Pyroxenite with pervasive dikelets of PRVK mixed with MGNT and lesser APTT. Actual grade is 12 percent TiO_2, but recoverable PRVK is only 8 percent (45 percent TiO_2, 0.5 percent Nb, and 1.15 percent REE).	Force and Lynd (1984); Wall Street Journal (1976).
---	Anorthosite intrusion.	ILMN, MGNT; HBLD, PRXN.	Ore occurs as small irregular veins to large tabular pods.	Do.
---	Anorthosite and gabbro intrusions.	ILMN, MGNT, GRNT; FLDP, PRXN, HBLD.	Ore is found in massive lenses, layered bodies, and disseminations.	Gross (1968); Force and Lynd (1984).

TABLE 9.—*Selected geologic and location information from*

Site name	Latitude longitude	Deposit type	Host rock	Age of mineralization
		UNITED STATES—Continued		
Trail Ridge (Starke and Highland) deposit.	30°02′N., 74°03′W.	Placer, marine	Aeolian sand; PLEIS	PLEIS
Tucker-Poplar Lake deposit	48°10′N., 90°40′W.	Magmatic, basic, irregular/stratiform, massive.	Gabbro; Duluth Complex; PROT.	PROT

ISMI records for titanium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	References
		UNITED STATES—Continued		
Basin	Shoreline, aeolian dune.	ILMN, LCXN, RUTL, ZRCN, KYNT, SLMN, STRL; QRTZ.	Well-sorted, crossbedded, unconsolidated sand impregnated with humate, 8 to 20 m thick. Avg grade 2.5 to 3 percent HM. ILMN contains 64.5 percent TiO_2.	Pirkle and Yoho (1970); Force and Garnar (1985).
Keweenawan Rift.	Gabbroic intrusive	ILMN, MGNT; PRXN, FLDP.	Ore occurs as segregations in oxide-rich gabbro. Deposit is in only one subunit of the enormous Ti-rich Duluth Complex (area over 5,100 km^2).	Fantel and others (1986).

Abbreviations used throughout this table include:
---, No information available; t, metric tons; conc, concentrate
Abbreviations for *mining method* are:
S, surface; U, underground; N, not yet producing.
All percentages refer to titanium dioxide 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 titanium dioxide; year of production (or range of years used to estimate average annual production); 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 titanium dioxide; years of reported cumulative production; degree of accuracy (accurate (Acc) or estimate (Est)).

Site name	Year of discovery	Mining method	Year of first production	Commodities	Annual production (in 1,000 t)
			AUSTRALIA		
EAST COAST					
Agnes Water deposit	1956	N	None	ILMN, ZRCN, RUTL	None
Bridge Hill Ridge deposit	Mid-1950's	S	1974	RUTL, ILMN	None
Fraser Island	1956	S	1971	RUTL, ZRCN	None
Moreton Island	1950's	N	1957	RUTL, ILMN, ZRCN	None
North Stradbroke Island	1950's?	S	1966	RUTL, ZRCN	RUTL: 78.0; 96 percent; 1983–84; Est.
Stockton deposit	1962	N	None	RUTL, ZRCN	None
Tomago deposit	1965	S	1972	RUTL, ZRCN, ILMN	RUTL: 29.21; 1979–83; Acc. ILMN: 11.615; 1979–83; Acc.
WEST COAST					
Barrambie deposit	1960	N	None	Ti-V-MGNT, ILMN, GOLD	None
Capel (AMC) deposit	1954	S	1956	ILMN, ZRCN LCXN, MNZT	ILMN: Included with Eneabba (AMC). SYN RUTL: 44.79; 92 percent; 1981–84; Acc.
Capel North deposit	1954	S	1964	ILMN, LCXN, ZRCN	ILMN: 408; 1980–83; Acc. LCXN: 2.2; 70 percent; 1980–83; Acc. LCXN: 10.88; 91 percent; 1980–83 Acc.
Dunkley/Norton deposit	1954?	S	1984	ILMN, ZRCN, LCXN, MNZT	ILMN: 140; 54 percent; 1985; Est (max capacity).
Eneabba (Allied) deposit	1968	S	1974	ILMN, RUTL, ZRCN	RUTL: 39.9; 96 percent; 1983–84; Acc. ILMN: 220.3; 59 percent; 1983–84; Acc.

from ISMI records for titanium deposits and districts

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 titanium dioxide (unless otherwise indicated); year of estimate (R indicates year of reference in which estimate appears).

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

Anatase............ANTS	Hematite...........HMTT	Monazite...........MNZT	Sulfides............SLPD
Apatite............APTT	Ilmenite...........ILMN	Perovskite..........PRVK	Synthetic rutile.....SYN RUTL
Cassiterite..........CSTR	Kyanite............KYNT	Pyrite.............PYRT	Titanomagnetite.....Ti-MGNT
Gold..............GOLD	Leucoxene..........LCXN	Rare-earth elements..REE	Zircon.............ZRCN
Garnet.............GRNT	Magnetite..........MGNT	Rutile.............RUTL	
Heavy minerals.....HM	Molybdenite........MLBD	Sillimanite.........SLMN	

Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
	AUSTRALIA—Continued	
None	ILMN: 1,731; R1E; 1978. RUTL: 292; R1E; 1978.	Undeveloped property. 20,000 t/yr RUTL conc is possible.
RUTL: 151.809; 1974-83; Acc.	RUTL: 250; R1E; 1984. ILMN: 102; R1E; 1973.	Most of these resources are unavailable due to environmental restrictions. Mining ceased in 1983; future mining appears unlikely.
RUTL: 44.292; 1971-75; Acc.	RUTL: 762.7; R1E; 1976. RUTL: 27; R2E; 1976.	Operation ceased due to government environmental restrictions.
RUTL: 3.0; 96 percent; 1957-58; Acc.	RUTL: 680.3; R1E; 1977. ILMN: 1,310; R1E; 1977. RUTL: 185; R1M; 1977. ILMN: 463; R1M; 1977.	Undeveloped property. Restrictions as above.
RUTL: 1,280; 96 percent; 1966-84; Est.	RUTL: 1,489; R1E; 96 percent; 1984 (former AMC resources not included—unavailable).	CRL acquired AMC assets on island in February 1985 and is currently expanding operations with development on new leases. Future looks very promising.
None	RUTL: 42.8; R1E; 1978 (additional R2E resources).	Production of about 35,000 t/yr RUTL and 40,000 t/yr ZRCN expected in 1985 by Mineral Deposits Ltd.
RUTL: 382.5; 1972-83; Acc. ILMN: 104.2; 1972-83; Acc.	RUTL: 340; R1E; 1983R. ILMN: 145; R1E; 1983R.	Further mine life of 15 yrs. ILMN has relatively high Cr content and is not used for metal or pigment.
None	ORE: 27,000; R1E; 15 percent; 1972	Ore also contains 26 percent Fe and 0.7 percent V_2O_5. Feasibility study underway. Titania slag, SYN RUTL, low-Mn iron, and flake V_2O_5 products are possible.
ILMN: 1978-84 included with Eneabba (AMC). ILMN: 3,332; 55 percent; 1956-77. SYN RUTL: 398.5; 92 percent; 1978-84; Acc.	ILMN: Included with Eneabba (AMC)	SYN RUTL produced at Capel from ILMN from both Capel and Eneabba mines. Expansion of SYN RUTL capacity to eventual 230,000 t/yr underway. Capel ILMN is 55 percent TiO_2.
ILMN: 4,198; 54 percent; 1962-83; Acc. LCXN: 212; 70-91 percent; 1962-83.	Company proprietary	Mine to close in 1987. Annual production includes Yoganup Extended deposit; cumulative production includes Yoganup Central and Extended deposits.
ILMN: 150; 54 percent; 1984-85; Est.	----- do. -----	Production commenced late 1984.
RUTL: 348.2; 96 percent; 1974-83; Est. ILMN: 2,645; 59 percent; 1974-83; Est.	ORE: 116,000; R1E; 10 percent HM; 1983. RUTL: 1,200; R1E; 96 percent; 1983. ILMN: 5,200; R1E.	Projected mine life of 19 more years.

TABLE 10.—*Selected production and mineral resource information*

Site name	Year of discovery	Mining method	Year of first production	Commodities	Annual production (in 1,000 t)
			AUSTRALIA—Continued		
Eneabba (AMC) deposit	1968	S	1974	ILMN, RUTL, ZRCN.	RUTL: 27.26; 96 percent; 1981–84; Acc. ILMN: 141.16; 55–60 percent; 1978–84; Acc.
Gingin deposit	1971	N	None	ILMN, RUTL, ZRCN.	None
Jurien deposit	1971	S	1975	RUTL, ILMN, ZRCN.	None (1978–85)
Waroona deposit	---	S	1985	ILMN, ZRCN, LCXN.	---
Yoganup Extended deposit	1954	S	1972	ILMN, LCXN, ZRCN, MNZT.	Included with Capel North deposit.
			BANGLADESH		
Cox's Bazaar-Moiskal Island deposit	1961	S	1975 (pilot plant).	RUTL, LCXN, ZRCN, KYNT.	RUTL: 0.06; 78–89 percent; 1977; Acc (pilot plant).
			BRAZIL		
Campo Alegre de Lourdes deposit	---	N	None	ILMN, LCXN, V_2O_5	None
Catalao deposit	---	N	None	ANTS, APTT, Nb.	None
Mataraca deposit	1970?	S	1984	ILMN, ZRCN, RUTL.	ILMN: 30; 1984; Est. RUTL: ?
Patrocinio deposit	1955	N	None	ANTS, APTT, Nb.	None
Salitre deposit	Pre-1966	N	None	ANTS, APTT, LCXN, Nb.	None
Tapira deposit	1955	S	1983	APTT, ANTS, LCXN, Nb, REE.	ANTS: 15; 90 percent; 1984; Est (pilot plant).
Vitoria district	---	S	Pre-1925	ILMN, RUTL, ZRCN, MNZT.	ILMN: 17; 55–60 percent; 1980–83; Est. RUTL: 0.275; 96 percent; 1980–83; Est.
			CANADA		
Kellogg Property deposit	1954	N	None	Ti-V-MGNT, ILMN.	None
Lac de la Blache deposit	1954	N	None	ILMN, Ti-V-MGNT	None

from ISMI records for titanium deposits and districts—Continued

Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
	AUSTRALIA—Continued	
RUTL: 399.93; 96 percent; 1974–84; Acc. ILMN: 1,850; 55–60 percent; 1978–84; Est. ILMN: 416.4; 60 percent; 1974–77; Acc.	RUTL: 1,642; R1E; 96 percent; 1984. ILMN: 10,172; R1E; 55–60 percent; 1984.	Resources include other areas owned at Capel and east coast (as of 1984). Eneabba ILMN —60 percent TiO_2; ILMN used for SYN RUTL not included.
None	ILMN: 1,800; R1S; 1976. RUTL: 170; R1S; 1976.	Development being deferred until a definite market is established.
RUTL: 15.6; 1975–77; Acc.	ILMN: 1,200; R1M; 1984R.	Inactive since 1977. Resumption of mining in near future not considered likely.
None (pre-1985).	Company proprietary	Production commenced in September 1986.
Included with Capel North deposit.	----- do. -----	Continuation (?) of Yoganup Central mine which closed in 1976. Substantial lower grade resources in nearby leases.
	BANGLADESH—Continued	
RUTL: 0.6; 78–79 percent; 1975–84; Est.	HM: 402.8; R1E; 28.9 percent ILMN, 3.7 percent. RUTL, 3.1 percent LCXN; 1976. HM: 400; R2E; 28.9 percent ILMN, 3.7 percent RUTL, 3.1 percent LCXN; 1976.	Production from pilot plant only. Government announced $7 million (U.S. dollars), 5-year development plan in 1985. Resources are in 250-km coastline; 2.2 million metric tons HM. ILMN is of an unsaleable grade for pigment production (41 percent TiO_2).
	BRAZIL—Continued	
None	ORE: 60,000; R2E; 20 percent; 1981R.	Finland's Outokumpu was reported to be showing great interest in development of V resources in 1979, but no plans as of 1984. Resources may reach 500 million metric tons of ore.
None	Probably similar to Tapira deposit.	Development would probably depend on the success of the ANTS concentrate to be produced from the Tapira deposit. Deposit may be mined for the underlying APTT.
ILMN: 60; 1984–85; Est. RUTL: ?	---	ILMN to go to a local TiO_2 plant.
None	ORE: 30,000; R1E; 28 percent; 1984R. R2 resources included with Tapira deposit.	A 64,000-t/yr ANTS concentration plant has been deferred indefinitely due to lack of markets.
None	ORE: 153,000; R1E; 23.5 percent; 1984R. R2 resources included with Tapira deposit.	Deposit held in reserve while CVRD develops the Tapira deposit. May be mined for underlying APTT.
ANTS: 30; 90 percent; Est.	ORE: 193,800; R1E; 22.4 percent; 1984R. TiO_2 (ANTS): 51,300; R2; 1981R.	A 500,000-t/yr ANTS plant is currently being built at Araxa (35 km N). Brazil hopes to develop an export market for ANTS. Deposit currently being mined for the underlying APTT. R2 resources refer to all ANTS deposits in Brazil.
ILMN: 344; 55–60 percent; 1925–83; Acc. RUTL: 24; 96 percent; 1932–83; Acc.	---	Prior to 1984, this district was the only Ti-producing area in Brazil.
	CANADA—Continued	
None	ORE: 73,440; R1S + R2S; 10.0 percent; 1975.	Ore contains 31.27 percent Fe and 0.50 percent V_2O_5. Titanium could be produced as a byproduct of vanadium, but there are no development plans.
None	ORE: 71,668; R2S; 20.5 percent; 1964.	No development plans.

TABLE 10.—*Selected production and mineral-resource information*

Site name	Year of discovery	Mining method	Year of first production	Commodities	Annual production (in 1,000 t)
CANADA—Continued					
Lac du Pin Rouge deposit	1955	N	None	ILMN, HMTT, Ti-MGNT.	None
Lac Tio deposit	1946	S	1951	ILMN, HMTT	SLAG: 734; 71 percent; 1978–82; Acc.
Magpie Mountain deposit	1953	N	None	MGNT, ILMN, V	None
St. Urbain district	1872	S	1940	ILMN, RUTL, HMTT.	None (1978–86)
Suncor deposit	1778	S	1967	Crude oil, S, V, Ni, LCXN, ILMN, RUTL, ZRCN.	None
Syncrude deposit	1778	S	1978	Crude oil, S, V, Ni, LCXN, ILMN, RUTL, ZRCN.	None
CHINA					
Beihai district	---	S	1966	ILMN, RUTL, ZRCN, MNZT.	ILMN: 20–30; 54 percent; 1978–82; Est. RUTL: 0.03–0.04; 94 percent; 1978–82; Est. SYN RUTL: 1.0; 88–90 percent; 1977–82; Est.
Heishan deposit	---	---	---	Ti-V-MGNT	---
Langping De Miao deposit	---	---	---	Ti-V-MGNT	---
Panzhihua deposit	---	S	1980	V-Ti-MGNT, ILMN, Ni, Co.	ILMN: 50; 46.4 percent; 1980–81; Est.
Sai-Lao district (Quoinghi)	Pre-1940	S	1958	ILMN, RUTL, ZRCN, MNZT.	ILMN: 10; 52 percent; 1981–82; Est. RUTL: 0.035; 90 percent; 1981–82; Est.
Wuzhaung (Wanning)	Pre-1940	S	1965	ILMN, RUTL, ZRCN, MNZT.	ILMN: 10; 51 percent; 1981–82; Est. RUTL: 0.04; 88 percent; 1981–82; Est.
Xun Jiang deposit	1975	N	None	ILMN, RUTL, ZRCN, MNZT.	None
Zhanjiang district	---	S	Approx 1960.	ILMN, RUTL, ZRCN, MNZT.	ILMN: 35; 52 percent; 1980–82; Est. RUTL: 0.13; 90 percent; 1980–82; Est.

from ISMI records for titanium deposits and districts—Continued

Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
	CANADA—Continued	
None	ORE: 34,800; R1S; 17 percent; 1980. ORE: 124,000; R2S; 7 percent; pre-1972.	Hemo-ILMN ore can be beneficiated to 38 percent TiO_2 + 45 percent Fe; Ti-MGNT ore to 68.3 percent Fe and 0.7 percent TiO_2. No development plans.
SLAG: 15,936; 71 percent; 1950–82.	ORE: 88,800; R1E; 32–34 percent (38 percent Fe); 1978–79R. ORE: 130,000; R2E; 27–32 percent (31–37 percent Fe); 1978–79R.	The grade of titania slag ("Sorelslag") was increased to 80 percent TiO_2 in 1983. Pig iron is also produced at average 500,000 t/yr. A steel plant is proposed.
None	ORE: 276,800; R1S; 10.5 percent; 1973R. ORE: 846,800; R2S; 10.5 percent; 1973R.	Resources represent total from the four local deposits and contain 43 percent Fe, 0.2 percent V_2O_5, 1.5 percent Cr. Low grade and impurities make development unlikely.
ORE: 553; 30.5 percent; 1940–77; Est.	ORE: 22,836; R1S; 30.5 percent; 1974.	Year of last production 1977. Resource figure represents aggregate of all deposits in the district. Cumulative production is approximate.
None	OIL SAND: 880,000; R1E; 1 percent HM; 1984.	Ti minerals are recoverable from scroll tailings that remain after the recovery of bitumen from the oil sand. HM content (approx) 35 percent LCXN, 30 percent ILMN, 30 percent ZRCN, 7 percent RUTL.
None	OIL SAND: 1,600,000; R1E; 1 percent HM; 1984.	Some 94,000 t of Ti minerals could be recovered from 700,000 t/yr of scroll tailings. HM content as above.
	CHINA—Continued	
ILMN: 285; 54 percent; 1966–82; Est. SYN RUTL: 5; 88–90 percent; 1977–82; Est. RUTL: 0.3; 94 percent; 1966–82; Est.	ILMN: 8,400;R1M; 46–48 percent; 1982. RUTL: 11;R1M; 94 percent; 1982.	Political resistance to mechanized mining could arise from farmers who mine the sands by hand. Resources are approx 50 percent in beach, 50 percent in river sands.
---	ORE: 10,000; R2E; 1984R.	Referred to in list of major Ti mines of China. Ore grade is estimated at 10 percent TiO_2 (BMR).
---	Included with Heishan deposit.	Do.
ILMN: 100; 46.4 percent; 1980–81; Est.	ORE: 1,070,000; R1E; 8–10 percent; 1982R. TiO_2: 96,300; R1E; 1982R. TiO_2: 450,000; R2E; 1982R.	ILMN reclaimed from MGNT tailings (7 million t/yr, 8.5 percent TiO_2). Only 10 percent of annual tailings used. Poor V recovery rates. Plans are to increase ILMN production and possibly add a pigment plant, a 10,000-t/yr sponge-metal plant, and a 3.2-million-t/yr steel plant.
ILMN: 120; 1973–82; Est. RUTL: 0.4; 90 percent; 1973–82; Est.	ILMN: 5,000; R1E; 41 percent; 1982R. RUTL: 50; R1E; 90 percent; 1982R.	Sand is hand-mined by farmers.
ILMN: 220; 51 percent; 1965–82; Est. RUTL: 0.93; 88 percent; 1965–82; Est.	ILMN: 5,000; R1E; 30–33 percent; 1982R. RUTL: 50; R1E; 88 percent; 1982R.	In the past, mechanized mining and concentration has been used to supply up to one-third of plant feed.
None	ILMN: 4,000; R1E; 45 percent; 1982R.	Government is interested in developing deposit. Mechanized mining is likely. ILMN concentrate is 53.5 percent TiO_2.
ILMN: 1,000; 52 percent; 1962–82; Est. RUTL: 3.5; 90 percent; 1962–82; Est.	ILMN: 10,000; R1E; 40 percent; 1982R. RUTL: 100; R1E; 90 percent; 1982R.	Figures refer to production from, and potential feedstock to, the five processing plants. Sand is mined by farmers.

TABLE 10.—*Selected production and mineral-resource information*

Site name	Year of discovery	Mining method	Year of first production	Commodities	Annual production (in 1,000 t)
			FINLAND		
Otanmaki deposit	1938	U	1953	ILMN, V-MGNT, PYRT.	None (1985) ILMN: 164; 45 percent; 1983 Acc.
			INDIA		
Chatrapur deposit	---	S	1984?	ILMN, RUTL, SLMN, MNZT, ZRCN.	SYN RUTL: 100; 1985; (max capacity). RUTL: 10; (max capacity).
Chavara deposit	---	S	1932	ILMN, RUTL, ZRCN, MNZT, SLMN.	ILMN: 142; 60.4 percent; 1981; Est. RUTL: 8.2; 93.0 percent; 1981; Est.
Manavala-kurichi deposit	---	S	1911	ILMN, RUTL, ZRCN, MNZT, GRNT.	ILMN: 65; 54.1 percent; 1984; (max capacity). RUTL: 1.5; 93 percent; 1984; (max capacity).
			ITALY		
Piampaludo deposit	1977	N	None	RUTL, GRNT, PYRT, ILMN.	None
			MADAGASCAR		
Tamatave district	None	S	1958	ILMN	None
			MALAYSIA		
Perak-Selangor district	---	S	1932	CSTR, ILMN, ZRCN, MNZT.	ILMN: 180; 54 percent; 1983-84; Est.
			MEXICO		
Pluma Hidalgo deposit	1939	N	None	ILMN, RUTL	None
			MOZAMBIQUE		
Pebane district	---	S	1958	ILMN, RUTL, ZRCN, MNZT.	None
			NEW ZEALAND		
Barrytown deposit	1860's	N	None	GOLD, ILMN, ZRCN, MNZT.	None
Westport deposit	1860's	N	None	GOLD, ILMN, ZRCN, MNZT.	None

from ISMI records for titanium deposits and districts—Continued

Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
	FINLAND—Continued	
ILMN: 3,450; 45 percent; 1953–83; Est.	ORE: 17,000; R1E; 13 percent; 1979R.	Mine closed, probably during 1984, due to low prices.
	INDIA—Continued	
---	ORE: 240,000; R1E; 9.5 percent ILMN, 0.5 percent RUTL; 1982R. ILMN: 22,800; R1E; 51 percent; 1982R. RUTL: 1,200; R1E; 96 percent; 1982R. ORE: 350,000; R1E; 9.5 percent ILMN, 0.5 percent RUTL; 1982R.	220,000 t/yr ILMN to be converted to 100,000 t SYN RUTL. Plants expected to be in operation by mid 1988. A chloride-route TiO_2 plant expected by late 1980's.
ILMN: 2,000; 60.4 percent; 1969–84; Est. RUTL: 120; 93.0 percent; 1969–84; Est.	ILMN: 35,000; R1E; 59.8 percent; 1985R. RUTL: 3,000; R1E; 93.0 percent; 1985R.	Current production from two plants; I.R.E. (major) and K.M.M.L. (minor, but expansion to 100,000 t/yr ILMN by 1990). ILMN has disadvantage of high Cr_2O_3 content (0.17 percent).
ILMN: 800; 54.1 percent; 1967–84; Est. RUTL: 20; 93 percent; 1967–84; Est.	---	Cumulative production from I.R.E. only; other foreign-owned companies possibly back to 1911. High Cr_2O_3 in ILMN (0.09 percent). Deposit much smaller than Chavara.
	ITALY—Continued	
None	ORE: 150,000; R1E; 4 percent RUTL; 1977. ORE: 300,000; R2E; 4 percent RUTL; 1977.	Feasibility studies still underway. Industrial grade GRNT occurs as major byproduct. The rock is exceptionally strong and abrasive.
	MADAGASCAR—Continued	
ILMN: 371; 1958–67.	(Possibly about 100 million metric tons ILMN.)	Joint venture between the government and Canada's QIT-Fer et Titane. Feasibility studies are underway. Possibility of a 300,000-t/yr ILMN mine by 1989. ILMN to be converted into 200,000-t/yr of 90-percent TiO_2 slag in Canada.
	MALAYSIA—Continued	
ILMN: 4,200; 54 percent; 1956–84; Est.	ILMN: 10,000; R2E; 54 percent; 1984.	ILMN extracted from tin tailings ("amang"). Production may decrease as a result of current (1986) excess supply of tin.
	MEXICO—Continued	
None	ORE: 3.82; R1E; 50 percent; 1984R. ORE: 65; R1E; 24.5 percent; 1984R. ORE: 1,000; R1S; 5 percent; 1984R.	Feasibility study underway April 1984. Mexican government is keen to develop mineral prospects. Mexico has a 35,000-t/yr pigment plant.
	MOZAMBIQUE—Continued	
ILMN: 25; 1958–60; Est. RUTL: None?	ILMN: 30,000; R2E; 1984R. RUTL: 2,000; R2E; 1984R.	Development is proposed by the government, but no formal plans have been announced. A further 50 million metric tons of ILMN is present offshore.
	NEW ZEALAND—Continued	
None	ILMN: 7,000; R2E; 46 percent; 1984R.	Raw ILMN is unsaleable due to inclusions and low grade but is highly susceptible to acid leaching. A pilot plant to process the ILMN directly into TiO_2 pigment is planned for 1985–87. Further development depends on its success. Drilling to define resources is underway. Gold avg 0.06 g/t.
None	ILMN: 10,000; R2E; 46 percent; 1984R. ILMN: 7-21,000; R2S; 46 percent; 1978R.	R2E deposits are in Holocene sands on or near present shoreline. R2S deposits are in PLEIS sands, inland. Raw ILMN is unsaleable as at Barrytown deposit. Further development depends on success of Barrytown pilot plant.

TABLE 10.—*Selected production and mineral-resource information*

Site name	Year of discovery	Mining method	Year of first production	Commodities	Annual production (in 1,000 t)
			NORWAY		
Rödsand deposit	1850	U	1900	V-MGNT, ILMN	None (from approx 1980) ILMN: 8.6; 39 percent; 1974–76; Acc.
Tellnes deposit	1954	S	1960	ILMN, Ti-MGNT, Cu-Ni SLPD.	ILMN: 585.2; 45 percent; 1981–83; Acc.
			ROMANIA		
Chituc deposit	---	S	Approx 1981	ILMN, ZRCN, GRNT.	ILMN: 5.6; 41 percent; 1982; Est.
Glogova-Sisesti district	---	N	None	ILMN, RUTL, ZRCN, MNZT.	None
Tigveni deposit	---	S	Approx 1981	ILMN	---
			SIERRA LEONE		
Gbangbama-Mogbwemo district	1954	S	1979	RUTL	RUTL: 71.8; 96 percent; 1983; Acc.
			SOUTH AFRICA		
Bothaville deposit	1955	N	None	ILMN, RUTL	None
Cape Morgan deposit	1954	S	1969	ILMN, RUTL	None
Ciskei Coast deposit	---	N	None	ILMN, RUTL	None
Richards Bay deposit	1968	S	1977	ILMN, RUTL, titania slag, low-Mn Fe.	SLAG: 381; 85 percent; 1983; Est. RUTL: 56; 1983; Est.
Transkei Coast deposit	---	N	None	ILMN, RUTL	None
Umgababa deposit	1948	S	1955	ILMN, RUTL	None
West Cape Coast deposit	1970	N	None	ILMN, RUTL	None
			SOVIET UNION		
Afrikanda deposit	Pre-1950	---	---	Ti-MGNT, PRVK	---
Dnepropetrovsk district	Pre-1957	S	1960	ILMN, RUTL, ZRCN.	ILMN: 250; 50–60 percent; 1981; Est. RUTL: 30; 95 percent; 1981; Est (refers to total Ukraine production).

from ISMI records for titanium deposits and districts—Continued

Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
	NORWAY—Continued	
ILMN: 93.88; 39 percent; 1962–76; Acc.	ORE: 17,600; R1E; 3.6 percent; 1977.	Mine closed in approx 1980. The hemo-ILMN could not be physically beneficiated above 40 percent TiO_2 and was no longer saleable.
ILMN: 12,500; 45 percent; 1961–83; Est.	ORE: 350,000; R1E; 18 percent; 1984R.	Two titania slag plants with total production of 500,000 t/yr (one with 75 percent TiO_2) are to be developed in the region. Slight Cr impurity in ILMN concentrate imparts green color to TiO_2 pigment.
	ROMANIA—Continued	
ILMN: 20; 41 percent; 1981–84; Est.	ORE: 200,000; R1M; 0.51 percent; 1982R.	Annual production data as surmized by U.S. Bureau of Mines (1982). Ni + Cr contents are too high for pigment production. A beneficiation plant has been considered.
None	ORE: 340,000; R1M; 1.5 percent ILMN, 0.5 percent RUTL; 1982R.	The sands could be expected to contain 1.5 percent RUTL, 0.12 percent ZRCN. No development has been reported.
---	ORE: 50,000; R2E; 1.7 percent ILMN; 1982.	Resource estimates must be considered at 50 percent probability level. Production confirmed by Romanian government in 1982, but no figures are available.
	SIERRA LEONE —Continued	
RUTL: 235.1; 96 percent; 1979–83; Acc.	ORE: 140,000; R1E; 1.8 percent RUTL; 1977. RUTL: 2,500; R1E; 96 percent; 1977. RUTL: 23,000; R2; 96 percent; 1981R.	High royalty payments to government could affect the duration of mine life. Good potential for the development of additional resources, especially in other nearby deposits.
	SOUTH AFRICA—Continued	
None	ORE: 34,000; R1S; 33.0 percent ILMN, 0.24 percent RUTL; 1984.	Deposit is in a remote area.
ILMN: 16.5; 49.8 percent; 1969; Acc. RUTL: 0.59; 95.2 percent; 1969; Acc.	ORE: 64,000; R1S; 2.8 percent ILMN, 0.14 percent RUTL; 1984.	1969 was the only year of production. TiO_2 grades are generally too low and inconsistent for exploitation.
None	ORE: 64,000; R1S; 3.3 percent ILMN, 0.15 percent RUTL; 1984.	Grade is too low for exploitation.
SLAG: 2,000; 85 percent; 1978–83; Est. RUTL; 287; 1978–83; Est.	ORE: 1,694,000; R1E; 5 percent ILMN, 0.3 percent RUTL; 1984. ORE: 455; R1M; 3.5 percent ILMN, 0.34 percent RUTL; 1984.	South Africa's only Ti-mineral producing area. Plans to increase mining capacity by 50 percent and smelting capacity to 600,000 t/yr titania slag.
None	ORE: 149,000; R1S; 5.4 percent ILMN, 0.2 percent RUTL; 1984.	Remote area; economic viability depends on possible offshore loader.
ILMN: 390.95; 49.6 percent; 1955–63; Acc. RUTL: 14.58; 95.4 percent; 1955–63; Acc.	ORE: 44,000; R1S; 9.05 percent ILMN, 0.5 percent RUTL; 1984.	Operations ceased in 1963 due to technical problems and pollution of local resorts. No plans for redevelopment.
None	ORE: 100,000; R1S; 70 percent ILMN, 0.1 percent RUTL; 1984.	Remote area, but some prospects for mining
	SOVIET UNION—Continued	
---	ORE: 190,700; R1E; 9.6 percent; 1950. ORE: 435,000; R2E; 9.6 percent; 1950.	PRVK conc: 43-51 percent TiO_2. Ti-MGNT conc: 9 percent TiO_2. Only Ti-producing mine in Kola Peninsula.
ILMN: 2,500; 50-60 percent; 1975–84; Est. RUTL: 300; 95 percent, 1975–84; Est.	---	Ukrainian placer deposits provide the majority of Soviet Ti production. Conversion of ILMN to titania slag (83 percent TiO_2) at nearby Zaporozhye.

TABLE 10.—*Selected production and mineral-resource information*

Site name	Year of discovery	Mining method	Year of first production	Commodities	Annual production (in 1,000 t)
			SOVIET UNION—Continued		
Gusevogorsk deposit	1931	S	1963	Ti-V-MGNT, ILMN	ORE: 35,530; 1.15 percent; 1973–77; Acc. ILMN: 150; 44 percent; 1981; Est (total Ural Mountains).
Kachkanar deposit	Pre-1780	---	---	Ti-V-MGNT, ILMN	ILMN: Included with Gusevogorsk deposit.
Kamakorskoye deposit	1973	N	None	Ti-MGNT, ILMN	None
Kiev district	---	S	---	ILMN	As for Dnepropetrovsk district.
Kopansk deposit	Pre-1940	U	---	Ti-V-MGNT, ILMN	---
Pudozhgorsk deposit	Pre-1957	---	Approx 1960 (test mining)	Ti-V-MGNT	---
Shubino Village deposit	1936	---	---	RUTL, GRNT ILMN.	---
Svoranzkoye deposit	Pre-1952	N	---	MGNT, Ti-MGNT, ILMN.	---
Tsaginsk deposit	Pre-1959	N?	---	Ti-V-MGNT, ILMN	---
Yelet Ozero deposit	Pre-1970	N?	---	Ti-MGNT, ILMN	---
Zhitomir district	Pre-1957	S	Approx 1960	ILMN, RUTL	As for Dnepropetrovsk district.
			SRI LANKA		
Pulmoddai deposit	1920	S	1961	ILMN, RUTL, ZRCN, MNZT.	ILMN: 75.03; 54.5 percent; 1982–83; Acc. RUTL: 7.65; 96.8 percent; 1973–83; Acc.
			TANZANIA		
Liganga deposit	---	N	None	Ti-V-MGNT, ILMN	None

from ISMI records for titanium deposits and districts—Continued

Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
	SOVIET UNION—Continued	
ORE: 339,000; 1.15 percent; 1963–77; Acc.	ORE: 3,150,000; R1E; 1.5 percent; 1971.	Ore treated at Mount Kachkanar; concentrate contains 60 percent Fe, 3.3 percent V_2O_5, and 0.66 percent TiO_2 (only 50 percent recovery). Ti-sponge plant at Berezniki, 150 km to NW. Ti production is secondary to that for Fe and V.
---	ORE: 2,600,000; R1E; 1.3 percent; 1971 (R2E included with Gusevogorsk deposit).	Deposit was being prepared for mining (annual capacity 25 million tons) in 1978 and may now be in production. Ti production is secondary to that for Fe and V.
None	ORE: 70,000; R2; 5 percent ILMN; 1978R.	The area is considered promising for further exploration. Ti would be a byproduct of possible iron-ore exploitation.
---	---	As for Dnepropetrovsk district.
---	ORE: 19,200; R1E; 11 percent; 1955. ORE: 3,200; R2E; 11 percent; 1955. ORE: 78,500; R2S; 6 percent; 1955.	Mined until recently (Zitzman, 1977–78). Disseminated ores are now subeconomic in terms of the principal commodity, iron.
ORE: 1,600; 6.2 percent; 1965; Est.	ORE: 248,600; R1E; 6.2 percent; 1970. ORE: 68,000; R2E; 6.2 percent; 1970.	Some test mining but no industrial mining by 1978. Was being considered for V production (1.12 percent V_2O_5 in MGNT concentrate).
---	---	Technological difficulties prevented the use of the deposit in 1977, but some mining in 1973 is reported. Current status is unknown.
---	ORE: 484,000; R2E; 1.3 percent; 1975R.	Reserves also include 1,000 million metric tons of "prognosticated ore." Doubtful production in 1982 (U. S. Bureau of Mines, 1982). Open-pit mining possible with perspective capacity of 5 million t/yr. Active investigation in 1978.
---	---	The following concentrates can be produced; Ti-MGNT: 58 to 59 percent Fe, 11 to 12 percent TiO_2, 0.5 to 0.6 percent V_2O_5; ILMN: 40 to 50 percent TiO_2. Resources stated as "large."
---	---	Resources quoted as "large." The following concentrates can be produced: Ti-MGNT: 9.4 percent TiO_2, 58.3 percent Fe, 0.62 percent V_2O_5; ILMN: 41.6 percent TiO_2.
---	---	Conversion of ILMN to titania slag (83 percent TiO_2) at Zaporozhye near Dnepropetrovsk district.
	SRI LANKA—Continued	
ILMN: 685.3; 54.5 percent; 1973–83; Acc. RUTL: 78.3; 96.8 percent; 1973–83; Acc.	ORE: 3,000; R1E; 73 percent ILMN, 11 percent RUTL; 1984R. ILMN: 2,200; R1E; 54.5 percent; 1984R. RUTL: 330; R1E; 96.8 percent; 1984R.	An additional 1.3 million metric tons of ore is estimated offshore. A 150,000-t/yr ILMN/15,000-t/yr RUTL plant commenced in late September 1984. Development of an 85-percent TiO_2 titania-slag plant is possible.
	TANZANIA—Continued	
None	ORE: 49,000; R1E; 13 percent; 1981R.	Deposits were under investigation in 1981. They may form basis for an iron and steel industry in Tanzania.

TABLE 10.—*Selected production and mineral-resource information*

Site name	Year of discovery	Mining method	Year of first production	Commodities	Annual production (in 1,000 t)
			UNITED STATES		
Aurora deposit	1951?	N	None	ILMN	None
Bingham Canyon deposit	1887	S	1904	Cu, MLBD, RUTL	None
Brunswick deposit	1955?	N	None	ILMN, RUTL, LCXN, ZRCN.	None
Cumberland Island deposit	---	N	None	ILMN, RUTL, LCXN, ZRCN.	None
Green Cove Springs deposit	1969?	S	1972	ILMN, RUTL, LCXN, ZRCN, MNZT.	Company proprietary. Max capacity: ILMN: 60–70 LCXN: 10. RUTL: 30.
Kerr-McGee deposit	1956	N	None	ILMN, RUTL, ZRCN, MNZT.	None
Lakehurst deposit	1957	S	1962	ILMN, LCXN, RUTL, ZRCN.	None
Manchester deposit	1956	S	1973	ILMN, RUTL	None
Natchez Trace deposit	1956	N	None	ILMN, RUTL, ZRCN, MNZT, KYNT.	None
Oak Grove deposit	1956	N	None	ILMN, RUTL, ZRCN, MNZT, KYNT.	None
Piney River district	Pre-1880	S	1900	ILMN, APTT	None
Powderhorn deposit	About 1880	N	None	PRVK, Nb, REE	None
San Gabriel Mountain district	1927	S?	1927	ILMN, MGNT, V	None
Sanford Lake district	Pre-1826	S	1942	MGNT, ILMN, V	None
Trail Ridge (Starke and Highland) deposit.	1946	S	1949	ILMN, LCXN, RUTL, ZRCN, KYNT.	Withheld. Max capacity TiO_2: 160.
Tucker-Poplar Lake deposit	Pre-1880	N	None	ILMN, Ti-MGNT	None

from ISMI records for titanium deposits and districts—Continued

Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
	UNITED STATES—Continued	
None	TiO_2: 400; R1M; 1.3 percent of ore; 1986.	No current exploration or plans for development.
RUTL: None. ORE:1,386,000; 0.6 percent Cu; 1904–84.	RUTL: 3,600; r1S; 0.3 percent RUTL in ore; 1985.	RUTL has never been recovered. Mine closed in 1984 due to low copper prices. Potential for approx 50,000 t/yr RUTL as byproduct.
None	Company proprietary	Resources are in the R1M category.
None	ILMN: 1,120; R1M; 1 percent ILMN in ore; 1986. RUTL: 160; R1M; 0.1 percent RUTL in ore; 1986.	Deposit is in a national park, so future development appears unlikely.
Company proprietary	ORE: 400,000; R1E; 1.3 percent; 1984 ORE: 500,000; R2E 1 percent; 1984.	Resources include all Florida deposits. Production is expected to continue to 2011. A SYN RUTL plant is under consideration. Concentrates are sold to Du Pont and are used at their chloride-route TiO_2 plants.
None	TiO_2: Probably several million metric tons contained in ore.	Excellent prospects if fine-grain-size problem is overcome. Kerr-McGee has a SYN RUTL plant and a TiO_2 plant elsewhere in the United States.
ILMN: 1,320; 59 percent; 1962–76; Est. LCXN-RUTL: ---	ILMN: 298; R1M; 3.5 percent ILMN in ore; 1986. LCXN-RUTL: R1M; 78 percent; 1986.	Only lower grade material is left. No active exploration or plans for development.
---	ORE:100,000; R1E; 1.95 percent; 1984.	Production ceased in 1982. Asarco has no intention of ever returning, it is dismantling and selling all equipment.
None	TiO_2 (in ILMN): 2,780; R1M; 1968. TiO_2 (in RUTL): 280; R1M; 1968.	Deposit is in a State park, so outlook is not good.
None	TiO_2: Probably several million metric tons contained in ore (R2E).	Good prospects for development if fine-grain-size problem is overcome.
ILMN: 180; 43–51 percent; Est.	ILMN:10,000; R2S; 13–20 percent ILMN in ore; 1985.	Old plant is unlikely to reopen. A new modern smelting plant may be economically feasible, but no plans have been announced.
None	ORE: 246,000; r1M; 8 percent PRVK; 1976. ORE: 133,000; r2S; 8 percent PRVK; 1976.	Future of deposit depends on the development of an economic process for the conversion of PRVK to TiO_2.
ILMN: 10; 40+ percent; 1927–28; Acc.	TiO_2: 4,800; R1S; 12 percent ILMN in ore; 1985.	Development is unlikely as deposit is in a national forest and grade is generally too low.
ILMN: 10,000; 46 percent; 1942–82.	TiO_2: 8,600; R1E+R2E; 35 percent ILMN in ore; 1985.	ILMN concentrate has been stockpiled since 1983 when NL's TiO_2 plant at Sayreville closed. The ILMN is suitable for sulfate-route TiO_2.
----- do. -----------------------	Included with Green Cove Springs deposit.	Du Pont has two plants operating on the deposit. Production from Du Pont leases is expected to continue to 2010.
None	ILMN: 230; r1M; 11.9 percent ILMN in ore; 1985 ILMN: 1,710; r2S; 7 percent of ILMN in ore; 1985.	Enormous resources of Ti-MGNT ore containing 10 million metric tons TiO_2 are present over the entire Duluth Complex. A large amount could be recovered each year from tailings from base-metal mining.

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