



International Strategic Minerals Inventory Summary Report—Vanadium

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

Geologic Time Scale

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

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By I. Goldberg, E.C.I. Hammerbeck, L.S. Labuschagne,
and C. Rossouw

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FOREWORD

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

The report was prepared by I. Goldberg of the Minerals Bureau of South Africa (retired) and by E.C.I. Hammerbeck, L.S. Labuschagne, and C. Rossouw of the Geological Survey of South Africa (GSSA). It was edited by David M. Sutphin and transcribed by Dorothy J. Manley of the U.S. Geological Survey (USGS). Vanadium inventory information was compiled or supplied by Cindy Rossouw (chief compiler); Ulrich H. Krauss, Federal Institute for Geosciences and Natural Resources of the Federal Republic of Germany; George N. Breit, USGS; Richard J. Fantel, U.S. Bureau of Mines; C. Roger Pratt, Australian Bureau of Mineral Resources, Geology and Geophysics; and A. Sozanski, Canadian Department of Energy, Mines and Resources (EMR), Mineral Policy Sector (MPS). Additional contributions to the report were made by Antony B.T. Werner and D.E.C. King (retired), EMR, MPS; G.A. Gross, EMR, Geological Survey of Canada; and J. De La Fluente, Centro de Información de Recursos Naturales, as well as by S. Schindler Contardo, Servicio Nacional de Geología y Minería, Chile.



Director

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INTERNATIONAL STRATEGIC MINERALS INVENTORY SUMMARY REPORT

VANADIUM

By I. Goldberg,¹ E.C.I. Hammerbeck,² L.S. Labuschagne,² and C. Rossouw²

Abstract

Major world resources of vanadium are described in this summary report of information in the International Strategic Minerals Inventory (ISMI). ISMI is a cooperative data-collection effort of earth-science and mineral-resource agencies in Australia, Canada, the Federal Republic of Germany, the Republic of South Africa, the United Kingdom, and the United States of America. This report, designed to benefit geologists and policy analysts, contains two parts. Part I presents an overview of the resources and potential supply of vanadium based on inventory information. Part II contains tables of some geologic information and mineral-resource and production data collected by ISMI participants.

Vanadium's greatest application is as an additive in steel. During 1984, for example, 90 percent of the vanadium produced in the world was consumed in steelmaking. The Soviet Union and China are the only major steel producers of the world that meet significant proportions of their vanadium needs from domestic sources, albeit from relatively low-grade ores. Reliable economically exploitable world resources total greater than 22 million metric tons of vanadium pentoxide. Deposits of the titaniferous magnetite type are the most economically important, and of these the Bushveld Complex of South Africa is the principal vanadium resource. The high-grade tenor of the Bushveld ore renders South Africa the world's leader in vanadium resources and production. Present (1990) major primary production is confined to only four countries: South Africa, the Soviet Union (low-grade ore), the Peoples Republic of China (low-grade ore), and the United States (partly from imported materials). This production trend is likely to continue for many years.

PART I—OVERVIEW

INTRODUCTION

The reliability of future supplies of strategic minerals is of concern to many nations. This widespread concern led to duplication of effort in the gathering of information on the world's major sources of strategic mineral materials. To pool this 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. The program 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 vanadium in a format designed to benefit policy analysts and geologists. Knowledge of the geologic aspects of mineral resources is essential 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

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addresses the primary stages in the supply process for vanadium and includes considerations of vanadium demand.

The imprecise term "strategic minerals" 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. 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 reports on platinum-group metals, cobalt, titanium, natural graphite, lithium, and tin are now published. Additional studies on vanadium (this report), zirconium, tungsten, and advanced materials have been subsequently undertaken.

The data in the ISMI vanadium inventory were collected from August 1984 to April 1986 and updated in 1989. The report was submitted to the U.S. Geological Survey for editing and publication in September 1989. The information used was the best available in the various agencies of the participating countries that contributed to the preparation of this report. Those agencies are 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; the Australian Bureau of Mineral Resources, Geology and Geophysics; and the British Geological Survey, a component of the Natural Environment Research Council of the United Kingdom.

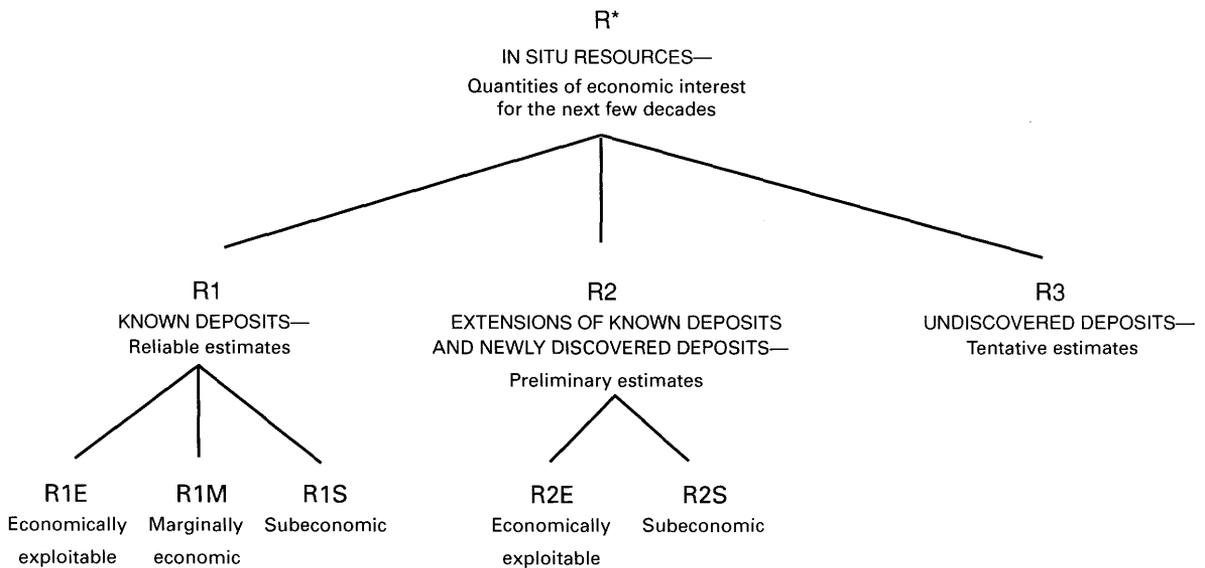
No geologic definition of a deposit (or district) is used for compiling records for this report. Deposits (or districts) are selected for the inventory on the basis of their present or expected future contribution to world supply. Records of all deposits compiled by ISMI participants meet this general "major deposit" criterion and are included in the inventory. In addition, and for the sake of completeness, summary information is provided on deposits that once were significant but whose resources are now considered to be substantially depleted. For most countries, inventory records are compiled on a deposit-by-deposit basis, but for some, such as the

Soviet Union, production and resources of vanadium cannot be distinguished. District totals are given for other deposits, for instance the Bushveld Complex, South Africa. Because the assignment of a specific number of records to the vanadium resources of a district or of an area was not done with the same detail by all compilers, comparisons among numbers of vanadium records in different geographic areas or among numbers of vanadium records and those of other commodities reported on in this series are not meaningful.

The ISMI record collection and this report on vanadium use the international classification system for mineral resources recommended by the United Nations Group of Experts on Definitions and Terminology for Mineral Resources (United Nations Economic and Social Council, 1979; Schanz, 1980). The terms, definitions, and resource categories of this system were established in 1979 to facilitate international exchange of mineral-resource data; the Group of Experts sought a system that would be compatible with the several systems already in use in several countries. Figure 1 shows the United Nations (U.N.) resource classification used here. This report focuses on category R1, which includes reliable estimates of tonnages and grades of known deposits. The familiar term "reserves," which many 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 proves to be significantly larger, sometimes even several times larger, than was established when the decision to mine was made. Experts who have a sound knowledge of a deposit and its geologic setting may infer that the deposit extends beyond the bounds reliably established up to that time. Tonnage estimates for such inferred extensions fall into category R2. For major deposits, ISMI records show R2 estimates in the few cases for which they are readily available. Category R3, postulated but undiscovered resources, is not dealt with in this report.

Not all companies or countries report resource data in the same way. Mining recovery from an orebody depends on individual conditions and can vary considerably, typically in the range of 75 to 90 percent for underground metal mining; that is, 10 to 25 percent of the in-place resources cannot be extracted. The World Bank economic classification of countries (World Bank, 1986, p. 180-181), which is based primarily on gross national product (GNP) per capita, is used in this and other ISMI reports to illustrate distribution of resources



*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).

and production according to economic groupings of countries. This classification was chosen because it relies primarily on objective economic criteria.

USES AND SUPPLY ASPECTS

Properties of vanadium.—Vanadium is widely distributed in the Earth's crust yet occurs rarely in sufficient concentration to be extracted profitably. In most instances, vanadium is produced as a byproduct of other commodities, such as iron, phosphorus, uranium, petroleum residues, coal, and aluminum. Pure vanadium metal is soft, malleable, and ductile; however, even small amounts of impurities render it hard and brittle. Due to its high melting point, approximately 1,900 °C, vanadium is regarded as one of the refractory metals, as are chromium, molybdenum, niobium, tantalum, and tungsten.

Uses.—The greatest application of vanadium is as an additive in steelmaking. Since vanadium is a strong carbide-forming element that can raise the strength of ferrite considerably, it can be used to greatly increase the hardness, ductility, and toughness of steel. Moreover, vanadium forms a very stable nitride, which improves the case-hardening characteristics of steel. About 90 percent of the 31,000 metric tons of vanadium produced in the

world in 1984 was consumed in steelmaking. Of this amount, 35 percent went into the manufacture of special purpose, particularly high-strength low-alloy (HSLA), structural steels, which exhibit yield points greater than 276 Megapascal and which acquire their strength either after hot-rolling or normal cooling. The amount of alloying elements, such as vanadium, molybdenum, niobium, and titanium, in HSLA steels is generally less than 0.1 percent. Vanadium, usually in the form of ferrovanadium or other vanadium alloys, is favored for use in these steels due to its strengthening effect, produced by precipitation hardening of the ferrite and refining of the ferrite grain.

The major use of HSLA steels is in the manufacture of high-strength pipelines for the transportation of oil and gas over long distances, especially under cold climatic conditions. Some HSLA steels display a dual-phase structure, which provides good cold-forming and welding characteristics; these steels are particularly suitable for use in automotive components and pipelines. Other HSLA steels are used for weight saving in general engineering structures, such as railway lines and reinforcing steels and in the aircraft industry. The demand for steels containing vanadium has increased considerably in the past decade and is expected to show a more

rapid growth in future years than the demand for mild steel (Duke, 1983).

Vanadium is used also in the production of certain tool steels, especially the low-alloy types (which have a higher hardening ability than straight carbon steels), and in high-speed tool steels, which can be used at elevated temperatures. The vanadium content in some of these steels is said to enhance wear resistance and increase their grain-coarsening temperatures to 1,030 °C. Other metallurgical applications are in various alloys, principally those of titanium (used in aircraft and in aerospace), in which the vanadium strengthens the pure titanium metal, and in cast iron, in which it counteracts graphitization and acts as a chill stabilizer.

Types of ferrovanadium.—Most vanadium used in industry is in the form of vanadium pentoxide or of ferrovanadium. Vanadium pentoxide (V_2O_5) is produced by blending milled ore, slag, or concentrate with sodium salt and then by roasting and leaching. Ferrovanadium (vanadium-carbon-iron alloy containing 50 to 86 percent vanadium) is produced by reducing vanadium pentoxide (by using carbon, silicon, or aluminum). Various types of ferrovanadium, distinguishable by their contents of vanadium, silicon, and carbon, are used in steelmaking. Among them are several proprietary products, such as Carvan, which contains 83 to 86 percent vanadium, 10 percent carbon, and 2 to 3 percent iron, and Ferrovan, which typically contains 42 to 43 percent vanadium, 6.5 percent silicon, 6.4 percent chromium, 3.6 percent manganese, 39.8 to 40.8 percent iron, and 0.7 percent carbon. Other registered vanadium products used in certain kinds of steelmaking are Nitrovan, a vanadium nitride additive, and Vanox, a modified vanadium oxide. Selected information on plants producing vanadium pentoxide and ferrovanadium is listed in tables 8 and 9 in Part II.

Vanadium pentoxide is used directly as a catalyst in certain oxidation reactions, for example, in sulfuric acid plants where sulphur dioxide is changed to sulphur trioxide and for conversion reactions of naphthalene to phthalic anhydride and of benzene to maleic anhydride. In addition to vanadium pentoxide, other vanadium compounds used in catalysis include ammonium metavanadate, vanadium oxytrichloride, and vanadium tetrachloride. Consumption of vanadium in catalysts, ceramics, and electronics (some vanadium compounds are superconductors) is about 700 metric tons annually and is likely to rise appreciably in the next decade. Vanadium is used also in welding rods and permanent magnets made from vanadium pentoxide and ferrovanadium, in photographic processes that require vanadium

chloride, as a colorant in ceramics and glass, and as a drier in ink, paint, and varnish.

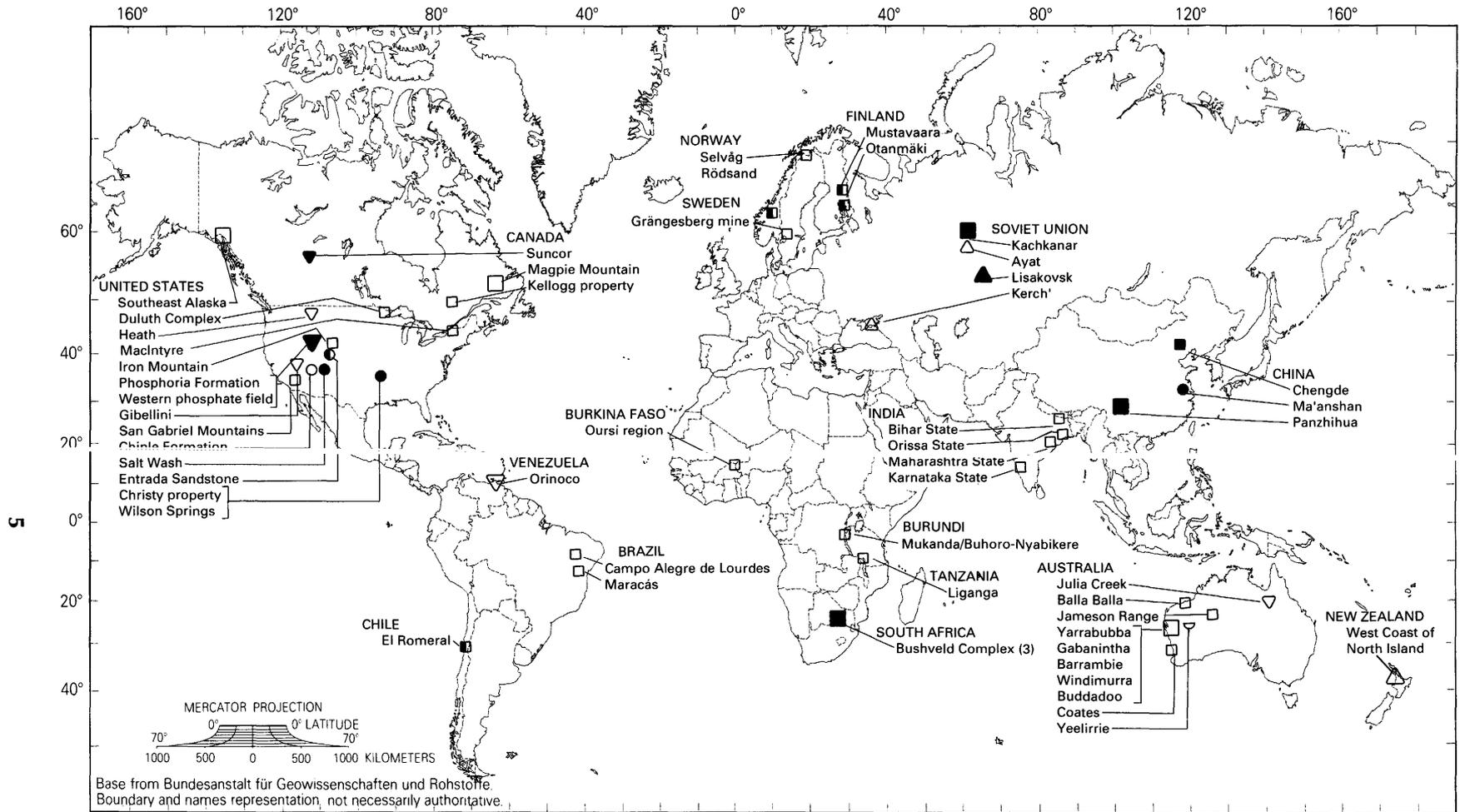
Substitution of vanadium.—Vanadium has specific technical advantages over possible substitute metals and is relatively inexpensive. Substitution, therefore, is likely only with the development of metals that are technically superior. In alloy steels, vanadium may be replaced by niobium, but, because each of these additives plays a particular role (for example, vanadium improves strength and niobium improves toughness by grain refining), substitution will be very limited.

Research has shown that titanium can be used as a substitute in certain pipeline steels; however, as with niobium, titanium is added primarily for grain refinement and does not provide the strengthening produced by vanadium. Consequently, titanium-bearing steels usually also contain vanadium. In titanium alloys, vanadium can be replaced by other metals, principally niobium, tantalum, and zirconium, but all of these are considerably more expensive and do not offer the versatile properties obtained by the use of vanadium. However, a new range of niobium-boron-titanium steels developed in Japan in the early 1980's is finding applications in markets that formerly used vanadium steels.

DISTRIBUTION OF VANADIUM DEPOSITS

The world map in figure 2 shows the location of major vanadium deposits and districts that have more than 10,000 metric tons of contained vanadium. Of the world's major steel producers, which include the People's Republic of China, Japan, the Soviet Union, the United States, and western Europe, the Soviet Union and the People's Republic of China are the only countries that fill significant proportions of their vanadium needs from domestic sources, albeit at relatively low-grade ore tenors. The districts shown in the United States, Finland, and Norway currently contribute little toward satisfying the vanadium demand of the industrial market economy countries.

Past producers and minor deposits.—Vanadium-bearing deposits occur on all the continents, including Antarctica (De Witt, 1985), but only 17 countries have defined resources exceeding 100,000 metric tons contained vanadium. Of these countries, five contain more than 95 percent of the world's total economic or nearly economic resources. These countries are, in order of decreasing importance, South Africa, the People's Republic of China, the United States, the Soviet Union, and Venezuela. Some very famous vanadium deposits, for example Mina Ragra, Peru, and Abenab, Namibia,



EXPLANATION

PRODUCER	NONPRODUCER	DEPOSIT TYPE	PAST PRODUCERS
■	□	Magmatic	■ ● Those with current resources >10,000 metric tons of contained vanadium
▲	△	Noncarbonaceous syngenetic sediment hosted	SIZE CLASSIFICATION
▼	▽	Carbon-rich syngenetic sediment hosted	□ Large to very large deposits >1,000,000 metric tons of contained vanadium
●	○	Epigenetic	□ Small to medium deposits 10,000 to 1,000,000 metric tons of contained vanadium
◐	◑	Surficial	

FIGURE 2. Location, geologic deposit type, and estimated resources of major vanadium deposits and districts in the world. Number in parentheses (following Bushveld Complex) indicates number of records (deposits and districts). Location names are from tables 6 and 7 in Part II.

TABLE 1.—*Past producers and minor deposits not included in the ISMI vanadium inventory*

Cumulative production: Includes some or all of the following items (separated by semicolons): cumulative production in metric tons of material mined; grade; years of production.

Resources: Includes some or all of the following items (separated by semicolons): resource in thousand metric tons; grade in percent V₂O₅ or percent vanadium.

—, not reported

Site name	Latitude	Longitude	Deposit type	Cumulative production	Resources
ANTARCTICA					
Dufek intrusion	82°30' S.	52°00' W.	Magmatic	None	—
FRANCE					
Saint-Rémy	48°58' N.	00°28' W.	Sediment hosted (noncarbonaceous).	—	3,000; 0.04 percent V (includes Jurques).
Segré.....	47°40' N.	00°52' W.	.....do.....	14,500; grade not reported; to 1975.	40,000; 0.08 percent V.
Soumont.....	48°59' N.	00°15' W.	.....do.....	946; grade not reported; 1978.	80,000; 0.05 percent V.
Mortain.....	48°39' N.	00°56' W.	.....do.....	—	100; 0.05 percent V.
INDIA					
Dulabera and Sialnoi group (Bihar).	22°30' N.	86°18' E.	Magmatic	—	250; 0.5–0.8 percent V ₂ O ₅ .
Joshipur group (Orissa)	21°59' N.	86°04' E.	.....do.....	—	250; 0.6–1.4 percent V ₂ O ₅ .
MOZAMBIQUE					
Tete.....	16°10' S.	33°31' E.	Magmatic	—	—
NAMIBIA					
Abenab-Abenab West.....	—	—	Supergene	1923 to 1947	56,600; 1–6 percent V ₂ O ₅ .
Berg Aukas .....	—	—	.....do.....	146,548 (concentrates); 1958 to 1978.	1,356; 0.6 percent V ₂ O ₅ .
NORWAY					
Solnördal (Sunnmøre district) (Møre og Romsdal Province).	62°40' N.	06°50' E.	—	None	5,000; 0.3 percent V.
PERU					
Minas Ragra	10°51' S.	76°33' W.	Epigenetic	22,680; 1907 to 1955.	>10,000; 1.75 percent V (important past producer).
SOUTH AFRICA					
Rooiwater Complex	23°56' S.	30°23' E.	Magmatic	None	0.45–1.1 percent V ₂ O ₅ .
SOVIET UNION					
Gusevogorsk	58°45' N.	59°23' E.	Magmatic	Only for iron	7.68; grade not reported.
Kusinskoe	55°20' N.	59°27' E.	.....do.....	Past producer	None.
Pervoural'sk	56°54' N.	59°58' E.	.....do.....	.....do.....	0.25; grade not reported.
ZAMBIA					
Broken Hill.....	14°27' S.	28°26' E.	Supergene	7,816; 1919 to 1952.	None (resources are exhausted).

are now depleted or have little chance of economic exploitation in the foreseeable future. For the sake of completeness of the record, such important past producers, as well as some documented minor deposits containing generally less than 10,000 metric tons contained vanadium, are not shown in figure 2 but are listed in table 1.

Classification of vanadium deposits.—A classification of vanadium-bearing deposits, based on genesis and host rocks, is given in table 2. The classification comprises magmatic, syngenetic, and epigenetic deposits as well as surficial deposits. In magmatic deposits, vanadium is contained mostly in magnetite and commonly, but not always, in titanomagnetite. Vanadium does not form discrete mineral grains but is probably present in solid solution, in which V^{+3} substitutes for Fe^{+3} (Reynolds, 1986). If the grade of V_2O_5 is sufficiently high, the vanadium has major economic significance. Titaniferous magnetite is used as a source of vanadium only in exceptional circumstances, such as when the vanadium grade is high or when the titanium phase can be physically separated prior to processing. Until recently, titaniferous magnetite was used in Norway as a source for titanium dioxide (TiO_2) pigment. It is presently used in Canada for this purpose.

Many bituminous or carbonaceous deposits contain significant amounts of vanadium. Since the vanadium is bound to and emplaced with the carbon or hydrocarbon in these deposits, it is categorized as syngenetic, irrespective of whether or not the hydrocarbons were transported into their present location. Carbonaceous syngenetic sediment-hosted deposits are the second most important sources of vanadium. Two types are distinguished: (1) oil shale, tar sand, and bituminous sediments, the largest of which are those in Venezuela, and (2) carbonaceous sediments that are nonbituminous or bitumen depleted and are not a potential source of carbonaceous material. Examples of this deposit type are found in the Phosphoria Formation in the United States. Noncarbonaceous sediments host the large vanadium deposits in the Soviet Union (in association with iron ores), but, apart from these and some marginal resources in New Zealand beach sands, this deposit type is insignificant.

Epigenetic deposits, particularly those in the Colorado Plateau, United States, were significant sources of vanadium, which was recovered together with uranium. Supergene and surficial deposits, for example Abenab and Berg Aukas, Namibia, were also major past producers. A small amount of vanadium is associated with uraniumiferous calcretes, such as those at Yeelirrie, Australia. Vanadium is recovered also from sludges produced

during processing bauxite for aluminum, but present and possible future production from this source is believed to be comparatively small.

Metallogeny of vanadium.—Vanadium mineralization is remarkably well defined in geological time (fig. 3). While there are numerous sedimentary iron formations and magnetite deposits in Archean rocks, none seem to contain economically significant concentrations of vanadium. Deposition of economically viable magmatic vanadium deposits commenced during the Early to Middle Proterozoic and was followed by an extended hiatus in vanadium accumulation prior to the development of Devonian and younger deposits (fig. 3). Available data (table 3 and tables 6 and 7 of Part II) suggest that deposits of magmatic magnetite in Precambrian gabbroic complexes constitute the single most important source of economically exploitable vanadium in the Earth's crust (fig. 3).

Most post-Devonian vanadium deposits are characterized by epigenetic vanadium in sandstone, as well as by syngenetic vanadium in carbonaceous shale and bituminous sediments. Since vanadium is closely associated with carbonaceous material in the largest post-Devonian deposits, the absence of epigenetic and syngenetic deposits prior to the Devonian can be related to the absence of well-developed terrestrial flora. Figure 4 shows the global distribution of major vanadium deposits and districts and indicates the economic class (based on GNP per capita) of countries where major vanadium deposits are located.

VANADIUM RESOURCES

Based on total contained V_2O_5 , about 67 percent of reported demonstrated global vanadium resources are in magmatic deposits. Of the remainder, at least 30 percent are in syngenetic sedimentary deposits, and less than 3 percent are in epigenetic and surficial deposits. In terms of reported vanadium pentoxide content, magmatic deposits account for 82 percent of the total known economic resources (R1E) and for almost 57 percent of reported resources in other categories of major vanadium deposits (table 3 and table 7 of Part II). Vanadium is produced as a primary commodity only in South Africa and possibly in some operations in Eastern European nonmarket economies; otherwise, vanadium is a byproduct. Hence, the criteria for economic, marginal, or subeconomic resources are in part determined by the demand for primary products, namely iron (minette ironstone), titanium, phosphate, uranium (sandstone and calcrete), bauxite, oil shale, and tar sand.

TABLE 2.—*Classification of vanadium geologic deposit types and examples*

Geologic deposit type	Important deposits	
Magmatic deposits		
Titaniferous magnetite	Balla Balla (Australia)	Magpie Mountain (Canada)
	Barrambie (Australia)	Mustavaara (Finland)
	Bushveld Complex (South Africa)	Otanmäki (Finland)
	Campo Alegre de Lourdes (Brazil)	Panzhuhua (China)
	Chengde (China)	Rödsand (Norway)
	Coates (Australia)	San Gabriel Mountains
	Gabanintha (Australia)	(United States)
	Grängesberg mine (Sweden)	Southeast Alaska (United States)
	Jameson Range (Australia)	Windimurra (Australia)
	Kachkanar (Soviet Union)	Yarrabubba (Australia)
	Kellogg property (Canada)	
Noncarbonaceous syngenetic sediment-hosted deposits		
Titanomagnetite beach sands	Beach deposits (New Zealand)	
Iron deposits.....	Kerch' (Soviet Union)	Lisakovsk (Soviet Union)
Carbon-rich syngenetic sediment-hosted deposits		
Oil shale, tar sand, bituminous sediments	Heath (United States)	Orinoco (Venezuela)
	Julia Creek (Australia)	
Carbonaceous sediments (not potential carbon producers) ..	Gibellini (United States)	Phosphoria Formation (United States)
Epigenetic deposits		
Alkaline complexes	Wilson Springs (United States)	
Other epigenetic deposits	Chinle Formation (United States)	Ma'anshan (China)
	Entrada Sandstone (United States)	Salt Wash (United States)
Supergene and surficial deposits		
Karst-fill base metal deposits.....	Abenab (Namibia)	Berg Aukas (Namibia)
Calcrete, gypcrete, and related surficial deposits	Yeelirrie (Australia)	
Bauxite deposits	Dnépropetrovsk (Soviet Union)	Various localities (India)

Table 3 shows the distribution of economically exploitable and marginally economic resources of major vanadium deposits by country and economic grouping. The table illustrates that the locations of economic and marginal vanadium resources are not consistent with the regions of major consumption such as steelmaking. The Soviet Union and China have 74 percent of worldwide R1E resources. This large proportion is partly because very low-grade ores are being mined in those countries and because all resources, even those which might be in the R2 category in western countries, are classified as R1E. In the western world, almost 100 percent of R1E vanadium resources are located in middle-income countries; virtually all of R1E resources are in the Bushveld Complex in South Africa. Industrial market economy countries have almost 25 percent of the marginal resources (R1M category), but most of these are in low-grade ores of the Phosphoria Formation in the western United States. The remainder of the R1M resources in major deposits is in upper middle-income countries, where 67 percent of the R1M resources are low-grade ores in Venezuelan oil deposits, 2 percent are in the El Romeral magmatic deposit in Chile, and the

remaining 31 percent are comprised of high-grade ores at a depth of more than 15 meters in the Bushveld Complex, South Africa.

The addition to world vanadium resources by discovery of new deposits is shown in figure 5. Increased demand for vanadium in the steel industry in the 1920's is reflected by a large number of discoveries. Also, the search for petroleum during this century led to the discovery of additional resources of vanadium, which, although currently considered marginally economic, for example those in Venezuela, may become economic in the future. Since a shortfall in supply is not foreseen, a major thrust in vanadium exploration is not likely unless production by the Soviet Union is curtailed.

The economic importance of vanadium deposits varies from country to country because vanadium is often recovered as a byproduct or because countries, such as China and the Soviet Union, apply strategic rather than economic criteria in developing minerals policy. The following country summaries describe the economic importance of various deposits within each country in the inventory, provide a history of their development, and give short descriptions of the deposits.

TABLE 3.—Known economic (R1E) and marginal (R1M) world vanadium resources listed by World Bank economic class of country, country, and resource classification

[Figures are in thousand metric tons of vanadium pentoxide. N.r. = not reported]

ECONOMIC CLASS ¹	Deposit type					Total
	Magmatic	Syngenetic sedimentary		Epigenetic	Surficial	
		Carbon rich	Noncarbonaceous			
Economically exploitable resources (R1E)²						
LOW INCOME						
China.....	3,448	N.r.	N.r.	840	N.r.	4,288
UPPER MIDDLE INCOME						
Brazil.....	42	N.r.	N.r.	N.r.	N.r.	42
Chile.....	486	N.r.	N.r.	N.r.	N.r.	486
South Africa ³	5,201	N.r.	N.r.	N.r.	N.r.	5,201
Venezuela.....	N.r.	N.r.	N.r.	N.r.	N.r.	N.r.
Subtotal.....	5,729	N.r.	N.r.	N.r.	N.r.	5,729
INDUSTRIAL MARKET						
Australia.....	N.r.	N.r.	N.r.	N.r.	10	10
Finland.....	N.r.	N.r.	N.r.	N.r.	N.r.	N.r.
Norway.....	N.r.	N.r.	N.r.	N.r.	N.r.	N.r.
United States.....	2	N.r.	N.r.	N.r.	N.r.	2
Subtotal.....	2	N.r.	N.r.	N.r.	10	12
EAST EUROPEAN NONMARKET						
Soviet Union.....	⁴ 9,150	N.r.	3,000	N.r.	N.r.	12,150
World total.....	18,329	N.r.	3,000	840	10	22,179
Marginally economic resources (R1M)²						
LOW INCOME						
China.....	N.r.	N.r.	N.r.	N.r.	N.r.	N.r.
UPPER MIDDLE INCOME						
Brazil.....	N.r.	N.r.	N.r.	N.r.	N.r.	N.r.
Chile.....	534	N.r.	N.r.	N.r.	N.r.	534
South Africa ³	8,400	N.r.	N.r.	N.r.	N.r.	8,400
Venezuela.....	N.r.	18,000	N.r.	N.r.	N.r.	18,000
Subtotal.....	8,934	18,000	N.r.	N.r.	N.r.	26,934
INDUSTRIAL MARKET						
Australia.....	293	N.r.	N.r.	N.r.	6	299
Finland.....	N.r.	194	N.r.	N.r.	N.r.	194
Norway.....	88	N.r.	N.r.	N.r.	N.r.	88
United States.....	740	7,338	N.r.	N.r.	N.r.	8,078
Subtotal.....	1,121	7,532	N.r.	N.r.	6	8,659
EAST EUROPEAN NONMARKET						
Soviet Union.....	N.r.	N.r.	N.r.	N.r.	N.r.	N.r.
World total.....	10,055	25,532	N.r.	N.r.	6	35,593

¹ Based principally on GNP per capita and, in some instances, on other distinguishing economic characteristics (World Bank, 1986, p. 180–181). Two other economic classes, high-income oil exporters and lower middle income, are not listed because those countries do not have reliable identified economic or marginal resources.

² Reliable estimates from identified deposits that have economically exploitable (R1E) or marginally economic (R1M) resources (fig. 1).

³ Includes Bophuthatswana.

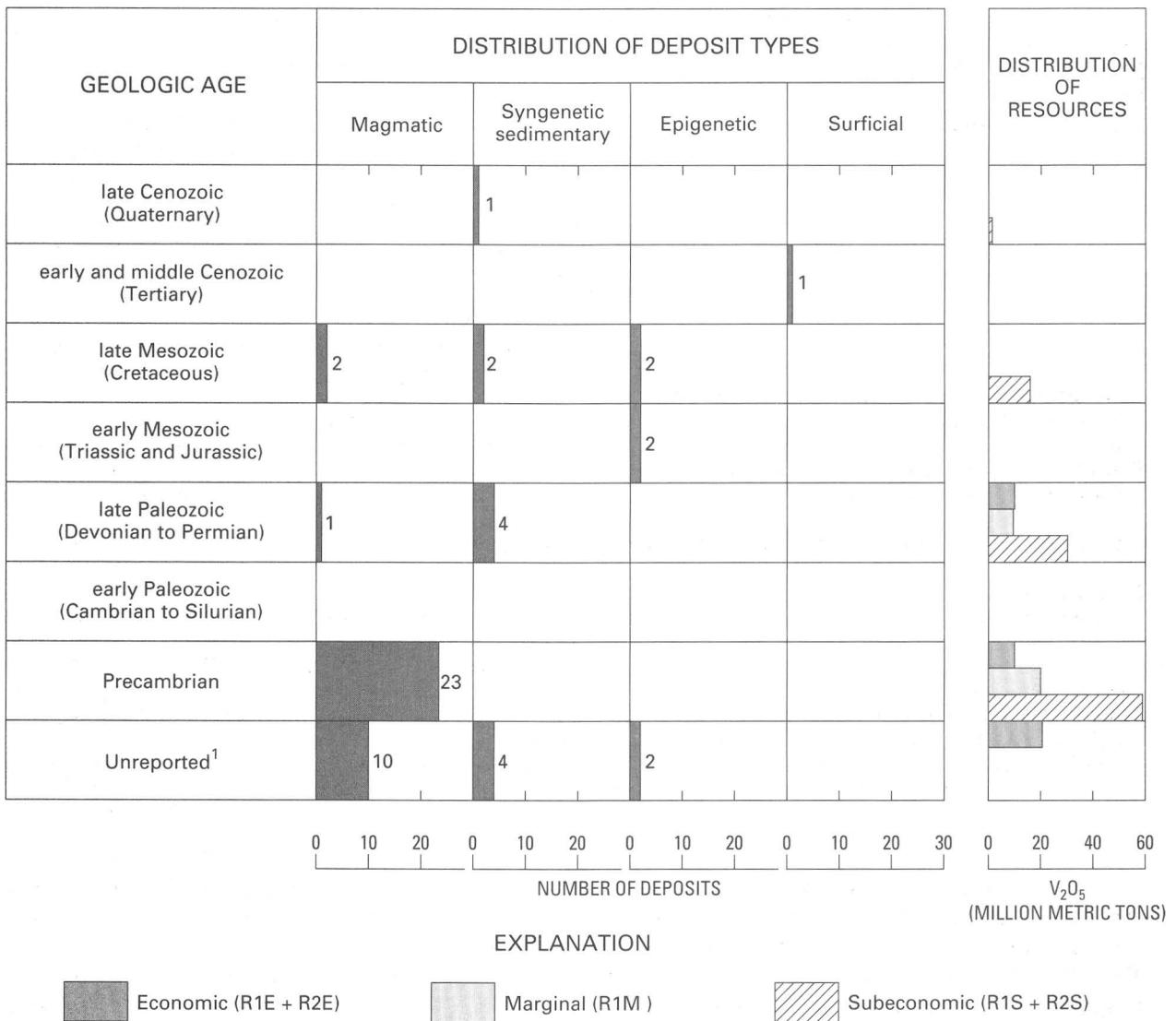
⁴ Includes R2E resources.

mining with processing plant improvements and favorable economic conditions.

Brazil.—Only two deposits are known, and these contain less than 1 percent of the total world resources. Exploitation of the largest deposit, at Campo Alegre de Lourdes, is constrained by a poor infrastructure (Gottschalk, 1980; Bureau de Recherches Géologiques et Minières, 1985).

Burkina Faso (previously Upper Volta).—Exploration for titaniferous magnetite delineated ten deposits in the Oursi region, notably at Tin Edia. Vanadium content of the magnetite in the Oursi region is lower than that in Burundi (Neybergh and others, 1980, p. 42), but the resources there are slightly larger.

Burundi.—Discovery of a vanadiferous magnetite deposit generated some optimism in the early 1980's

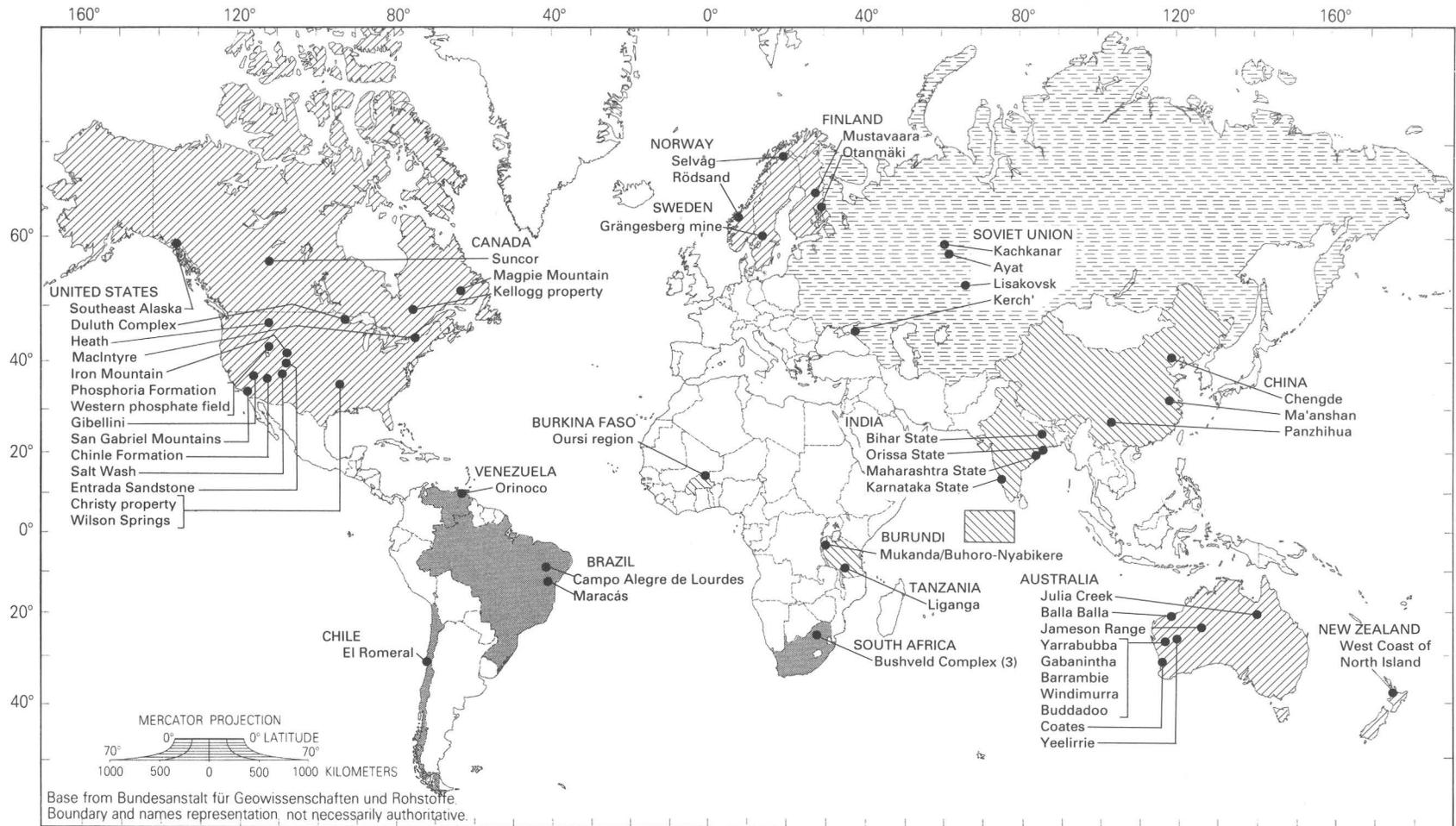


¹ No geologic age reported on the ISMI inventory record form.

FIGURE 3. Distribution of vanadium deposit types and current resources through geologic time.

Australia.—The largest deposit, which is a major vanadium resource, is a carbonaceous shale at Julia Creek where vanadium may be recovered as a byproduct from petroleum extraction. However, as a result of depressed oil prices and more promising north Queensland oil shales, this deposit is unlikely to be developed during the next decade (Pratt, 1987). Vanadium may also be recovered as a byproduct of uranium at Yeelirrie, but exploitation potential of this deposit is low compared with that of the large uranium deposits in the Northern Territory, at Olympic Dam in South Australia, and elsewhere. Present (1990) government policy prohibits

uranium mining except at the deposits at Nabarlek, Ranger, and Olympic Dam. Substantial resources of vanadium are contained also in titaniferous magnetite deposits in Western Australia. Possibly the largest resources (estimates have not been done) are in the Jameson Range, which is situated in a very remote locality on the eastern boundary of Western Australia (fig. 2). Other large deposits of substantially high grade are at Balla Balla, Barrambie, Buddadoo, Coates, and Gabanintha. Resources of vanadiferous laterite capping titaniferous magnetite were mined at Coates in the early 1980's and have the potential to support a resumption of



EXPLANATION



FIGURE 4. World Bank economic classification for countries in which the world's major vanadium deposits and districts occur (World Bank, 1986, p. 180–181). Number in parentheses (following Bushveld Complex) indicates number of records (deposits and districts). Location names are from tables 6 and 7 in Part II.

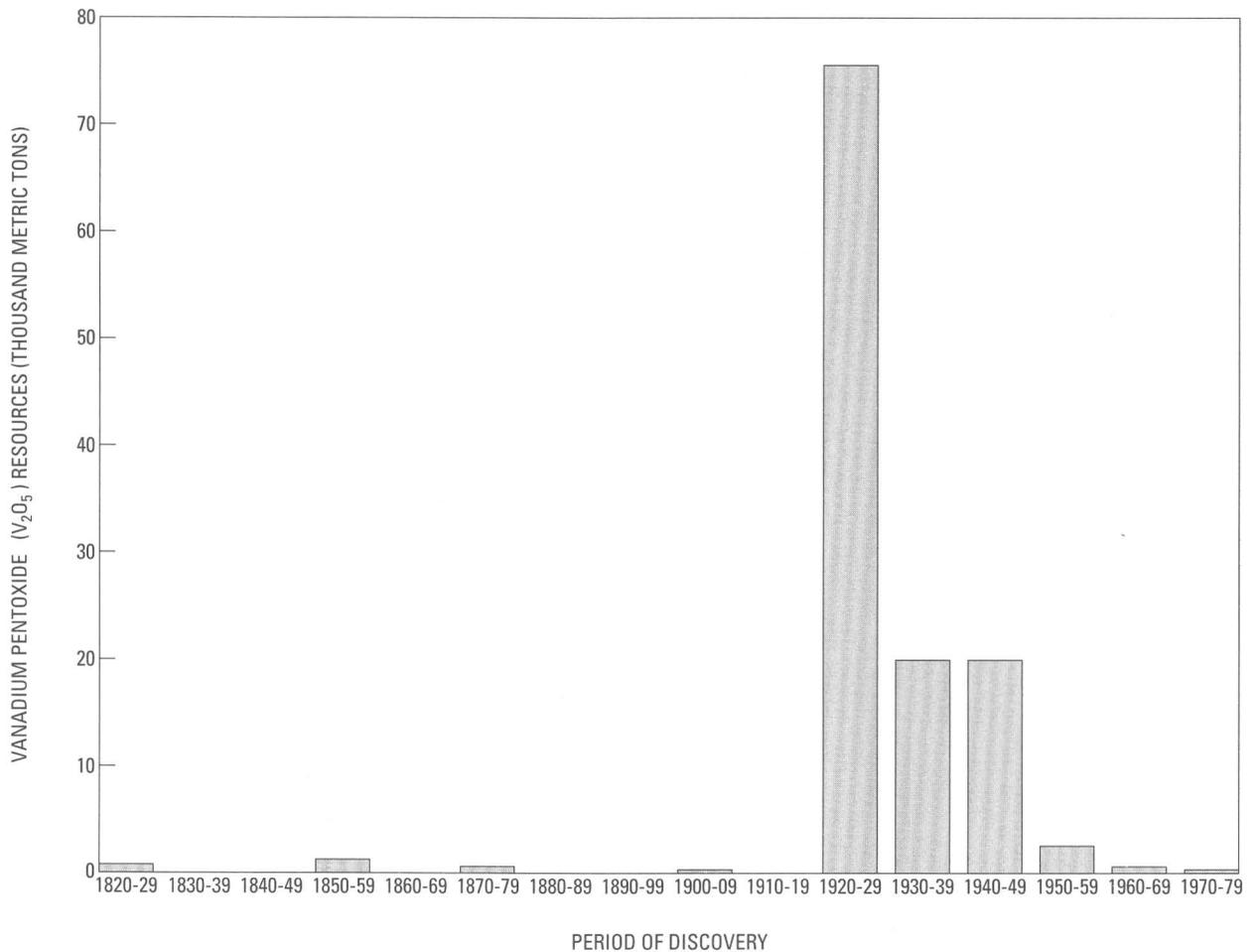


FIGURE 5. Additions to vanadium resources in the world's major deposits and districts according to their date of discovery.

since the grade was relatively high at 1.5 percent V_2O_5 . Resources are, however, small (0.04 percent of the world total), and poor infrastructure militates against early development (Mining Magazine, 1982).

Canada.—The best prospect for economic recovery of vanadium in Canada is the vanadiferous bitumen of the Alberta tar sands. While the bitumen itself contains only a few hundred parts per million V_2O_5 , the residue from petroleum extraction contains 2 to 4 percent V_2O_5 (Rose, 1973; Stemerowicz and others, 1976). The potential for vanadium extraction from vanadium-bearing titaniferous magnetites is very low because the grade is only 0.2 percent V_2O_5 at Magpie Mountain, the largest of the deposits in Canada. Material from the Kellogg property, where the grade is 0.5 percent V_2O_5 , however, can be upgraded to 1.5 percent V_2O_5 .

Chile.—El Romeral was a prime producer of magnetic iron ore. Concentrates for export yielded a minimum of 62 percent iron and contained from 0.6 to

0.8 percent V_2O_5 . Vanadium slag containing about 10 percent V_2O_5 (Schmidt and others, 1981) was produced and exported.

People's Republic of China.—Total resources are slightly more than 10 percent of the world total; the most important deposit is the titaniferous magnetite at Panzhihua in Sichuan Province. Resources are truly large—the deposit contains 80 percent of the Republic's total resources of vanadium—but the grade is relatively low (0.3 percent V_2O_5). Apart from iron, titanium, and vanadium, the deposit also contains small amounts of chromium, cobalt, nickel, and gallium, which may constitute byproducts (World Mining, 1980).

In the 1980's, China consistently produced about 4,000 metric tons of contained vanadium per year. Annual output of vanadium slag at Panzhihua was 70 percent of China's total vanadium production (Chin, 1982, p. 389). However, in 1991, China also imported slag for vanadium extraction. China has established itself

as a major exporter of vanadium; because domestic consumption is only one-third of total production, Panzihua contributes substantially toward foreign trade (Brady, 1981). The second largest vanadium producer is the Chengde, Hebei, steel mill, which treats ore that has been mined locally; the third largest is the iron deposit mined to serve the Ma'anshan, Anhui, steel mill (Brady, 1981, p. 55). In addition, small amounts of vanadium pentoxide have been produced since 1977 from sapropelic coals (Wang, 1980).

Finland.—Vanadium resources in magmatic deposits at Otanmäki and Mustavaara are relatively low grade at 0.36 and 0.25 percent V_2O_5 , respectively. Because of unfavorable market conditions, mining operations at both deposits were suspended in 1985 (Salo, 1986). However, if market conditions improve, the deposits can be marginally economic.

India.—Despite intensive exploration of numerous titaniferous magnetite deposits, resources are subeconomic and small compared to the world total. Indian bauxite may have potential as a source of vanadium since it contains between 0.01 and 0.2 percent V_2O_5 , but no resource estimate has been calculated (Fortnightly Journal of Industry and Commerce Review, 1979; Vasudev and Srinivasan, 1979).

New Zealand.—The iron sands in Pleistocene and Holocene modern beaches and raised fossil beaches (Williams, 1965) stretch along 500 km of the west coast of North Island and contain between 1 and 2 percent of the world's total vanadium resources. Mining operations for magnetite beneficiation are located at Waikato North Head, Taharoa, and at Waipipi (New Zealand Geological Survey staff, 1981), but no vanadium has been produced. Plans for recovery of vanadium from steel-making slag have been reported as part of New Zealand Steel Ltd.'s expansion, which was expected to be completed in 1986 (Sage, 1986). The company obtains its iron ore from Waikato North Head.

Norway.—The magnetite ore of Norway is western Europe's richest source of titanium, but the vanadium content is low (only as much as 0.2 percent vanadium in ore and 0.5 percent in concentrate). The Bamle metallogenic province contains the largest amount of vanadium in both ore and concentrate (Geis, 1971), but for 104 years the vanadiferous magnetite deposit at Rödsand in Möre og Romsdal Province was a source of iron and vanadium (United Nations Department of Economic and Social Affairs, 1970). Mining operations at Rödsand were suspended in 1982 because it had been operating at a loss (U.S. Bureau of Mines, 1982).

South Africa.—The Bushveld Complex contains the world's largest vanadium resources of both the R1 and R1E categories. These vast resources are a result of the remarkable persistency of vanadiferous magnetite, both laterally and in depth, and its anomalously high vanadium content, averaging 1.6 percent V_2O_5 but exceeding 2 percent V_2O_5 in places (Willemse, 1969).

The extent of Bushveld resources was not understood when a comprehensive summary of geological investigations in the Complex was published by Hall (1932). The presence of vanadium in magnetite had been first reported by Adam (1923), was studied in some detail by Schweltnus and Willemse (1943), and was depicted on the first mineral map of South Africa in 1959 (DeVilliers, 1959). Systematic prospecting was done in the 1960's and various resource estimates were made. On the basis of work by Schutte (1976), von Gruenewaldt (1977) estimated that the upper 30 meters of vanadium-bearing material contained about 16.8 million metric tons V_2O_5 . Recently, the resource base was revised to 7.2 million metric tons of vanadium metal of which 2 million metric tons are located in Bophuthatswana (MacCaskie, 1984). This figure comprises 3.4 million metric tons of demonstrated economic (R1E) and 3.8 million metric tons of marginal (R1M) vanadium metal resources in magnetite deposits containing more than 1.25 percent V_2O_5 that are less than 15 meters deep.

In the estimations by von Gruenewaldt (1977) and MacCaskie (1984), the giant Uppermost Magnetite Seam (No. 21) was not included in view of its relatively low vanadium content of 0.3 percent V_2O_5 . Such low grades are, however, normal for most vanadiferous magnetites throughout the world. In order to put the Bushveld Complex into world perspective, 46 million metric tons of V_2O_5 (Schutte, 1976) would be added to the subeconomic resources (R2S) if the Uppermost Magnetite Seam were included. In places, vanadiferous titanomagnetite is not confined to specific seams but is dispersed over a wide zone comprising numerous closely spaced seams, which are amenable to opencast mining.

In this inventory, South African R1E and R2E resources are calculated to a cutoff grade of 1.25 percent V_2O_5 , to vertical depths of 15 and 80 meters, respectively, and are in deposits amenable to outcrop working and opencast mining. R1M category comprises 15 to 20 meters depth extensions of R1E resources. R1S and R2S categories include down-dip extensions of minable seams to a vertical depth of 200 meters, all less well-prospected seams, and all lower grade titanomagnetite that has a cut-off value of 0.3 percent V_2O_5 to the same depth.

Soviet Union.—Little is known about the Soviet Union's vanadium deposits, but resources may be very large, although of low grade. The largest deposit and the largest producer is Kachkanar, a titanomagnetite deposit of iron ore in the Central Urals. Tonnages of 2.6 to 11.8 billion metric tons and grades between 0.08 and 0.35 percent vanadium in concentrate (0.14 to 0.63 percent V_2O_5) are reported (Metals Sourcebook, 1973). In this report (table 3 and table 7 of Part II), a grade of 0.39 percent V_2O_5 was used. Quoted resources were increased to 6.1 billion metric tons by Metals Sourcebook (1973). The minette iron ore mines at Lisakovsk and in Ayat in Kazakhstan are the second largest producers. According to Sokoloff (as quoted by Mineral Trade Notes, 1961), the Western Kazakhstan district has virtually unlimited resources of phosphoritic and oolitic brown ironstone suited for open-pit mining. Subsequently, Sokoloff (1963) stated that the iron ore at Kerch', Lisakovsk, and Ayat probably accounts for more than two-thirds of the 6.35 billion metric tons of the proven economic brown iron ore resource of the Soviet Union. Discounting 1 billion metric tons for Kerch', the resources at Lisakovsk and Ayat can be calculated as approximately 3.4 billion metric tons, which compares well to earlier published resources of 3.367 billion metric tons containing 0.1 percent V_2O_5 (Mineral Trade Notes, 1961; Strishkov, 1977 and 1979). In this report (table 3 and table 7 of Part II), resources of 3 billion tons at 0.1 percent V_2O_5 were used.

Vanadium pentoxide has been recovered as a byproduct in the production of alumina from bauxite at Dnépropetrovsk (U.S. Bureau of Mines, 1977), and the Soviet Government announced that a commercial process for vanadium recovery from oil shale had been developed (U.S. Bureau of Mines, 1984). If these resources, for which no estimates are available, and the ironstone at Kerch' are taken into account, the low-grade vanadium resources in the Soviet Union may be substantially greater than those given in this inventory.

Sweden.—The deposits at the Grängesberg mine are included in this inventory, but no vanadium production seems likely because of the low tenor of the ores.

Tanzania.—Four titaniferous magnetite bodies in the Njombe district have been prospected, but the resources are relatively small and the vanadium grade is low.

United States.—The United States ranks second in total world demonstrated resources (R1) but has a serious shortage of economic resources (R1E). Sandstone-hosted uraniferous deposits on the Colorado Plateau have been significant producers since the beginning of this century, and vanadium has been recovered from these

deposits as a byproduct of uranium since World War II. Resources at some of these deposits are depleted, while the depressed uranium market, which shows no sign of improvement, renders exploitation elsewhere uneconomic.

In 1986, the only source of vanadium production was the Phosphoria Formation in the western United States, where vanadium was a byproduct of phosphate processing. Total resources in the phosphate field are large and constitute approximately 3 percent of the world total. Alaskan titaniferous magnetite deposits also contain large low-grade resources of vanadium, but it is unlikely that these could be economically exploited in the foreseeable future.

Venezuela.—Because of an anomalously high vanadium content of 100 to 1,400 parts per million in the Maracaibo and Orinoco oil fields, Venezuela ranks fourth in total vanadium resources (R1). It should be noted that vanadium can be recovered from oil when it is concentrated in residues, for example in fly ash or flexicoke. It can also be recovered from poisoned catalysts in refineries. Estimates of Venezuela's oil resources differ widely from 500 billion barrels in place, of which 300 billion barrels are considered to be recoverable (Kapo and Lopez, 1973), to 1.5 trillion barrels containing 150 to 500 parts per million vanadium for the Orinoco field alone (U.S. Bureau of Mines, 1983).

Development of the Orinoco oil field and large-scale production of byproduct vanadium are underway, and production of vanadium pentoxide in flexicoke (presumably from the Maracaibo field) is almost 3,000 tons per year (U.S. Bureau of Mines, 1983). Using an in-place resource estimate of 500 billion barrels of heavy crude oil and an average vanadium content of 200 parts per million (Kapo and Lopez, 1973), the in-place vanadium resources are 14.4 million metric tons. The corresponding number for a recoverable resource of 300 billion barrels of oil is 8.64 million metric tons of vanadium metal contained in the crude oil.

Using further a production rate of 227 million barrels of oil per year and a concomitant byproduct vanadium pentoxide extraction of 3,000 metric tons per year (U.S. Bureau of Mines, 1983) and assuming a life span of 30 years, the economic vanadium resources in Venezuela are about 90,000 metric tons of vanadium pentoxide, or 50,400 metric tons of vanadium metal. The amount of vanadium recovered from this source was small when the United States was the only country processing both ash and flexicoking residues from Venezuelan oil. With the modernization of the Rotterdam refinery in the Netherlands, this production was expected to grow from 1986 on (U.S. Bureau of Mines, 1985).

Venezuela's vanadium resources can be used only in installations (mainly elsewhere in the world) that produce, or can procure, sufficient oil residues to warrant a vanadium extraction plant. The implications are, therefore, that only a relatively small proportion of this country's huge vanadium resources is economically recoverable.

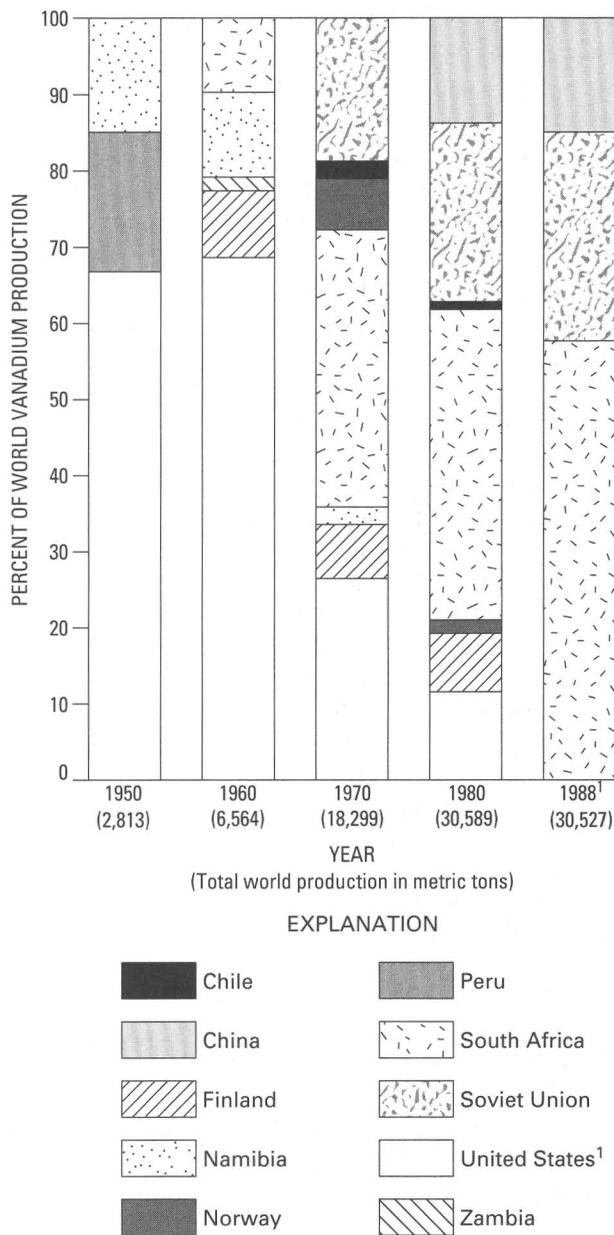
VANADIUM PRODUCTION

Large-scale commercial use of vanadium started in the early 1900's as a result of the development of tungsten-vanadium and chromium-vanadium tool steels, as exhibited in the United States in 1906. Further technological progress shortly thereafter helped to enhance the potential for vanadium as an alloy element and, with the discovery of the rich vanadium-bearing asphaltic deposits at Minas Ragra, Peru, in 1905, vanadium became a metal of economic significance and of specialized industrial use.

Production history.—An historical portrayal of world production, listed by country, is given in figure 6. In the United States, the first commercial production of vanadium additives for steelmaking commenced in 1909. Subsequently, increased usage in this field provided the stimulus for growth of the vanadium industry to its present dimension. Since 1960, the use of vanadium in nonferrous alloys, principally titanium alloys for jet engines and airframes, has become significant. In 1960, vanadium oxide was recovered in the United States by three companies at four plants. By 1980, there were 11 facilities in the United States, and these plants used mainly uranium-vanadium ores from the Colorado Plateau. However, production diminished significantly after the decline in the uranium market, and total U.S. production from primary ore was reduced to about 1,600 metric tons in 1984. An additional 1,700 metric tons of U.S. vanadium production, which came from processing fly ash, petroleum residues, and spent catalysts, increased to almost 2,700 tons in 1985 (Kuck, 1985).

Production in South Africa commenced in 1957 with output from an American-based company operating a mine at Kennedy's Vale in the Eastern Transvaal. The mine was closed in 1972 and was superseded by the Mapochs mine at Roossenekal. South Africa now has several plants, such as the Highveld Steel and Vanadium Corporation plant near Witbank, for smelting ore and vanadium recovery as slag and vanadium oxide. Vanadium output from South Africa is the largest in the world and is likely to remain so for many years.

The Soviet Union is the world's second leading vanadium producer after South Africa. However, few



¹ U.S. total in 1988 withheld to avoid disclosing company proprietary data; therefore, U.S. total is not included in world total.

FIGURE 6. Proportions of total world mine production of vanadium accounted for by countries that have major deposits and districts in the ISMI vanadium inventory, selected years 1950–88. (Reported production sources: U.S. Bureau of Mines, 1953–89; Hilliard, 1989. Note that information on Soviet Union production is not available prior to 1970.)

reliable production data are available. Furthermore, while the Soviet Union was once an exporter, it now relies on substantial imports to sustain its requirement. Principal deposits being worked, all of a low grade compared

with those elsewhere in the world, are Kachkanar, Kerch', Ayat, and Lisakovsk.

Finland has produced vanadium since 1953 and until the early 1980's was the third largest supplier in the western world. The sole operating company, Rautaruukki Oy, which is mostly state owned, had two mines—Ontanmäki and the Mustavaara. A low price for vanadium pentoxide is believed to be the main reason that the mines began phasing out production in about 1984 and finally closed in 1985.

The People's Republic of China assumed considerable importance as a vanadium producer and exporter in 1982 and 1983 after an extended absence from the market. However, vanadium pentoxide supplies from that country have since been irregular. The principal deposits being worked are those at Panzhihua in the southern part of Sichuan Province. Although the ore also contains cobalt, chromium, and nickel, which render metallurgical treatment difficult, the Chinese have developed an extensive iron- and steel-smelting complex that produces vanadium and titaniferous slag as byproducts. Available production and sales statistics are not exact, but estimates place annual output at about 5,000 metric tons of contained vanadium in vanadiferous slag.

Norway's sole producer, the Rödsand mine (owned by Elkem) ceased operations in 1982. Other former producers include those in Namibia, where operations ceased in 1978; Petrofina Canada, which recovered high-purity vanadium pentoxide from residual oils from Venezuela between 1965 and 1971; Mina Ragra in Peru, which was the world's principal vanadium producer from 1900 to 1955; the Coates mine in Western Australia, which was in production only from 1980 to 1981; Broken Hill in Zambia, which was in production from 1919 to 1952; and the Kusanskoe and Pervoural'sk deposits in the Soviet Union, which were exhausted during the 1960's.

Current production.—It is difficult to accurately deduce world primary production of vanadium due mainly to conflicting statistics from different published sources. Moreover, the Soviet Union and China, both major producers, do not disseminate statistical information on their vanadium production. Therefore, production figures quoted in this report for these countries are estimates based on scant reliable data.

The 54 vanadium deposits and districts in the International Strategic Minerals Inventory occur in 17 countries, of which South Africa, the United States, and the Soviet Union collectively accounted for more than 80 percent of the world's cumulative vanadium production. Figure 7 shows the production of vanadium from each of the producing countries included in the ISMI vanadium

inventory. Significant increases in production from South Africa and the Soviet Union for the periods shown cause the U.S. proportion of world vanadium production to be lower. This change was exacerbated further by a marked decline in U.S. production, particularly at uranium-vanadium mines.

Information on estimated cumulative production from 1950 through 1988 and world annual production for 1988 is shown in table 4. The country production data are grouped by World Bank economic class in table 5. Almost 38 percent of cumulative production since 1950 and more than 57 percent of 1988 production were from upper middle-income economic countries (almost totally from South Africa and lesser amounts from Argentina, Chile, and Mexico). The industrial market economy countries (predominantly the United States, Finland, and Norway and limited production reported by France and Australia) accounted for 30 percent of production since 1950 and an undisclosed portion (from the United States) of the 1988 production. Eastern European nonmarket economy countries (chiefly the Soviet Union) accounted for 22 percent of cumulative production and 29 percent of 1988 production. China, classified as a low-income economy country, contributed 7 percent to total production since 1950 and more than 13 percent to the world's

TABLE 4.—*Estimated world cumulative and annual mine production of vanadium, contained in ore and concentrate, for each country having a major vanadium deposit or district*

[Figures are in metric tons and may not add to totals shown due to rounding. Figures in parentheses are percent of column totals. N.r. = not reported, W = withheld to avoid disclosing company proprietary data, * = not in the ISMI vanadium inventory. Sources: U.S. Bureau of Mines, 1953–89; Hilliard, 1989]

Country	Cumulative production 1950–88	Estimated annual production 1988
South Africa	238,000 (36.5)	17,500 (57.5)
Soviet Union	143,000 (21.9)	8,800 (29.1)
United States ¹	138,000 (21.2)	W
China	46,000 (7.1)	4,100 (13.4)
Finland	44,300 (6.8)	N.r.
Namibia*	19,400 (3.0)	N.r.
Norway	12,300 (1.9)	N.r.
Chile	8,000 (1.2)	N.r.
Other producers ²	2,620 (0.4)	N.r.
Total	652,000 (100)	30,400 (100)

¹ The United States also recovered 1,500 metric tons from ash, petroleum residues, and spent catalysts—all primary vanadium. Country of origin of petroleum is not defined, although the United States was not the likely source.

² Production from countries, including Angola,* Argentina,* Australia, France,* Mexico,* Peru,* and Zambia,* having minor deposits.

TABLE 5.—*Estimated world cumulative and annual mine production of vanadium, contained in ore and concentrate, by World Bank economic class of country*

[Figures are in metric tons and may not add to totals shown due to rounding. Figures in parentheses are percent of column totals. N.r. = not reported, W = withheld to avoid disclosing company proprietary data, * = not in the ISMI vanadium inventory. Sources: U.S. Bureau of Mines, 1953–89; Hilliard, 1989]

Economic class ¹	Cumulative production 1950–88	Estimated annual production 1988
Low income.....	46,000 (7.1)	4,100 (13.4)
Lower middle income.....	21,700 (3.3)	N.r.
Upper middle income.....	246,000 (37.8)	17,500 (57.5)
Industrial market.....	195,000 (29.9)	W
Eastern European nonmarket.	143,000 (21.9)	8,800 (29.1)
Total.....	652,000 (100)	30,400 (100)

¹ Based principally on GNP per capita and, in some instances, on other distinguishing economic characteristics (World Bank, 1986, p. 180–181). Countries having reported vanadium mine production from 1950 to 1988 are, by economic class: low-income economies—China; lower middle-income economies—Angola,* Namibia,* Peru,* Zambia*; upper middle-income economies—Argentina,* Chile, Mexico,* South Africa; industrial market economies—Australia, Finland, France,* Norway, the United States; and Eastern European nonmarket economies—the Soviet Union. A sixth economic class, high-income oil exporters, is not listed because those countries do not have major demonstrated vanadium deposits.

total output in 1988. Lower middle-income economy countries have no major deposits and are not included in the inventory, but between 1950 and 1988 those countries (Angola, Namibia, Peru, and Zambia) accounted for about 3 percent of world vanadium production.

The maps in figures 8 and 9 show the locations of 49 vanadium pentoxide and (or) ferrovanadium processing plants in 20 countries. Of these facilities, 13 produce only vanadium pentoxide and 28 produce ferrovanadium. An additional eight plants produce both vanadium pentoxide and ferrovanadium. Several more countries are known to have facilities that produce vanadium pentoxide and ferrovanadium, but no information about these operations was reported. Locations and plant names are from tables 8 and 9 in Part II.

In studies of the structure of industrial markets, one way of measuring market concentration is to focus directly on observable dimensions, such as numbers of suppliers. The market concentration ratio, defined as the percentage of total industry sales or output contributed by the largest few firms (Scherer, 1970, p. 50–51), can be used for countries as well. Figure 10 shows the four-country and eight-country concentration ratios for 1913 and 1980 production of several nonfuel mineral

commodities. By these measures, vanadium ranked high among those mineral commodities controlled by a few producing countries in 1913. The four-country concentration ratio of vanadium production decreased from 1913, when the industry was in its infancy, to 1980 from 100 to 88 percent. The eight-country ratio remained at 100 percent for that period principally due to the large growth in output from Highveld's mine at Mapochs in South Africa and to expansion in production levels in the Soviet Union. These measures indicate that vanadium continues to rank high among those mineral commodities controlled by a few producing countries.

Present and probable future vanadium production from the major deposits and districts included in the International Strategic Minerals Inventory vanadium inventory are shown on the map in figure 11. Because the production in Finland, Chile, Namibia, and Norway ceased and the vanadium output from the United States declined, three countries, South Africa, the Soviet Union, and China, have become and will likely remain the dominant producers. Supplementary production is possible from Canada (for example, from mid-1990 to the spring of 1991, Carbovan Inc. extracted vanadium oxide from fly ash from the Suncor oil sands plant). In addition, more Venezuelan oil may be treated by the flexicoke process to yield substantial amounts of vanadium in the future. Vanadium may also be recovered as a byproduct in the alumina industry, notably in India and Hungary. In Australia, Western Mining completed major design work for development of the Yeelirrie uranium-vanadium deposit, but the project did not proceed due to government policy. However, production could recommence at Agnew Clough's Wundowie deposit (not in this inventory), which produced vanadium in 1981 but closed because of a downturn in the iron and steel industry. This supplementary production, however, will likely be low compared with production from South Africa. Chinese exports are irregular and unpredictable.

CONCLUSIONS

The strategic nature of vanadium stems from its superiority as an additive that provides high strength and durability in steel, particularly in high-strength low-alloy steels used in the manufacture of gas and oil pipelines, and automotive components, engineering structural steels and rails and in the aircraft industry. Movable resources of ores containing vanadium are confined to less than 10 countries, and only three countries, South Africa, the Soviet Union, and China, have more than 97 percent of the world total. Vanadium is an important strategic mineral in part because it cannot be substituted

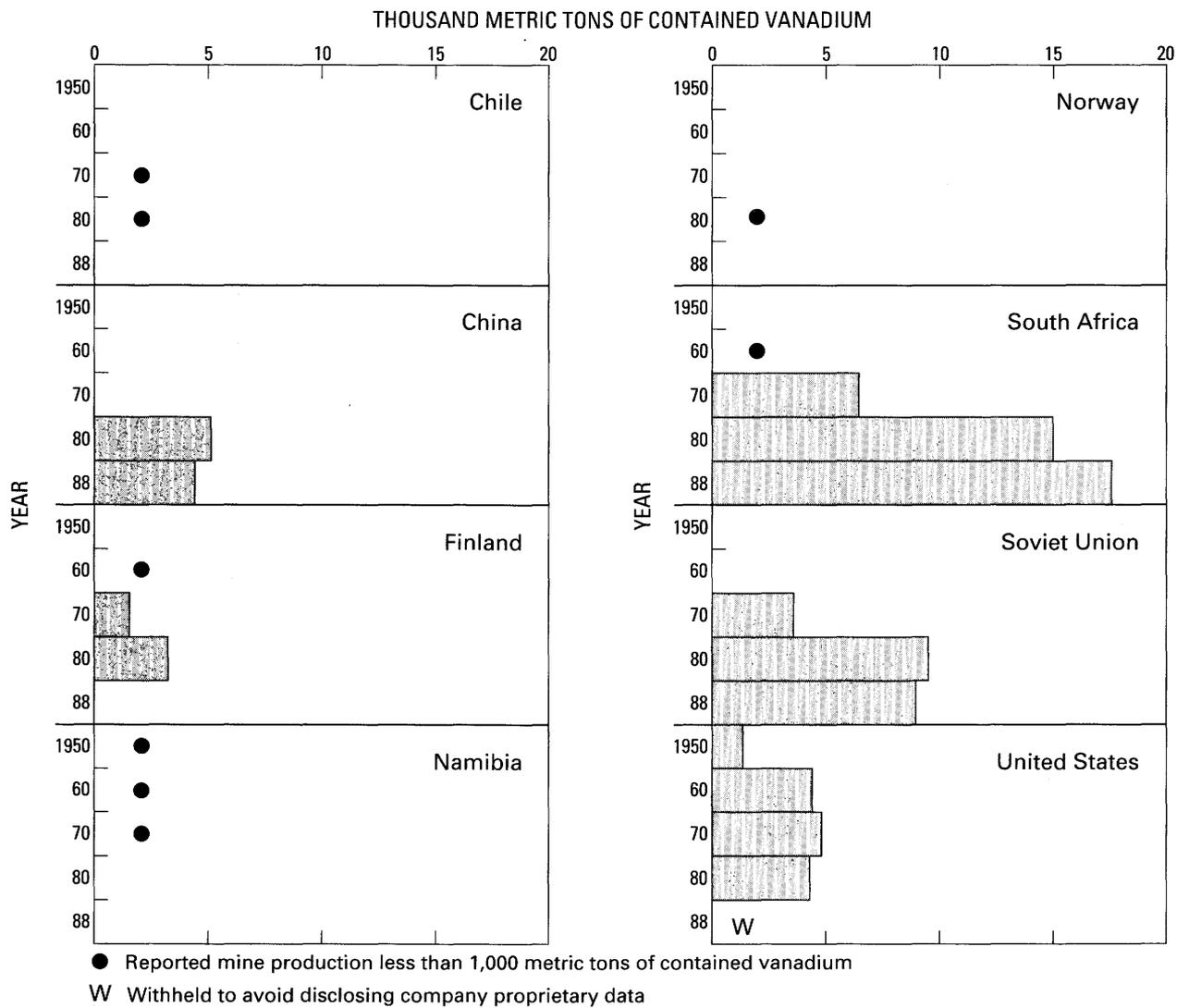


FIGURE 7. Vanadium production in countries that have major deposits and districts in the ISMI vanadium inventory, selected years 1950–88. Only those countries having reported production for the selected years are shown. Figures are calculated from reported ore production (U.S. Bureau of Mines, 1953–89; Hilliard, 1989).

for easily or economically. The world's most important vanadium deposits are of the titaniferous magnetite type. More than 70 percent of the cumulative world vanadium production since 1950 has been from this deposit type. Moreover, these magmatic ores constitute the predominant resource types.

World resources (R1E category) in major deposits and districts total more than 22 million metric tons of vanadium pentoxide. Although only 25 percent of this total is located in the Bushveld Complex of South Africa, this ore is high grade. If estimates of marginally economic resources (R1M) are included, the South African resources of 13.6 million metric tons give that

country world leadership in vanadium resources. Other countries having large resources are the Soviet Union, China, Venezuela, and the United States. The Soviet Union, once an exporter of vanadium, currently relies on imports to meet part of its requirements. China, which has consistently produced as much as 4,000 metric tons of contained vanadium per year since 1980, has been unable to maintain an export trade in the commodity. Concurrently, in the United States, there has been a sharp decline in coproduct output at uranium-vanadium mines. These factors, and increased demand in the United States and other industrialized nations, resulted in production shortfalls in some years.

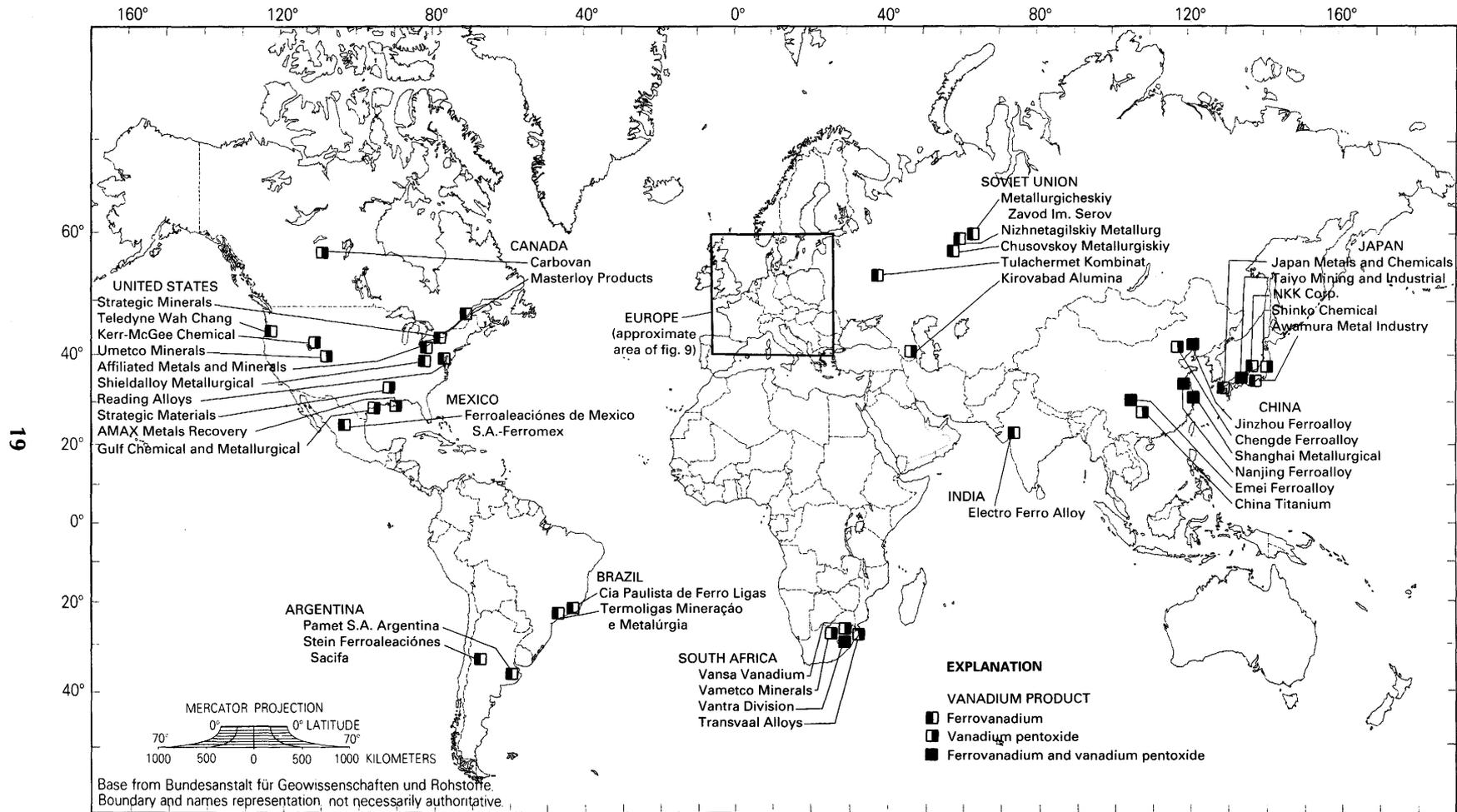
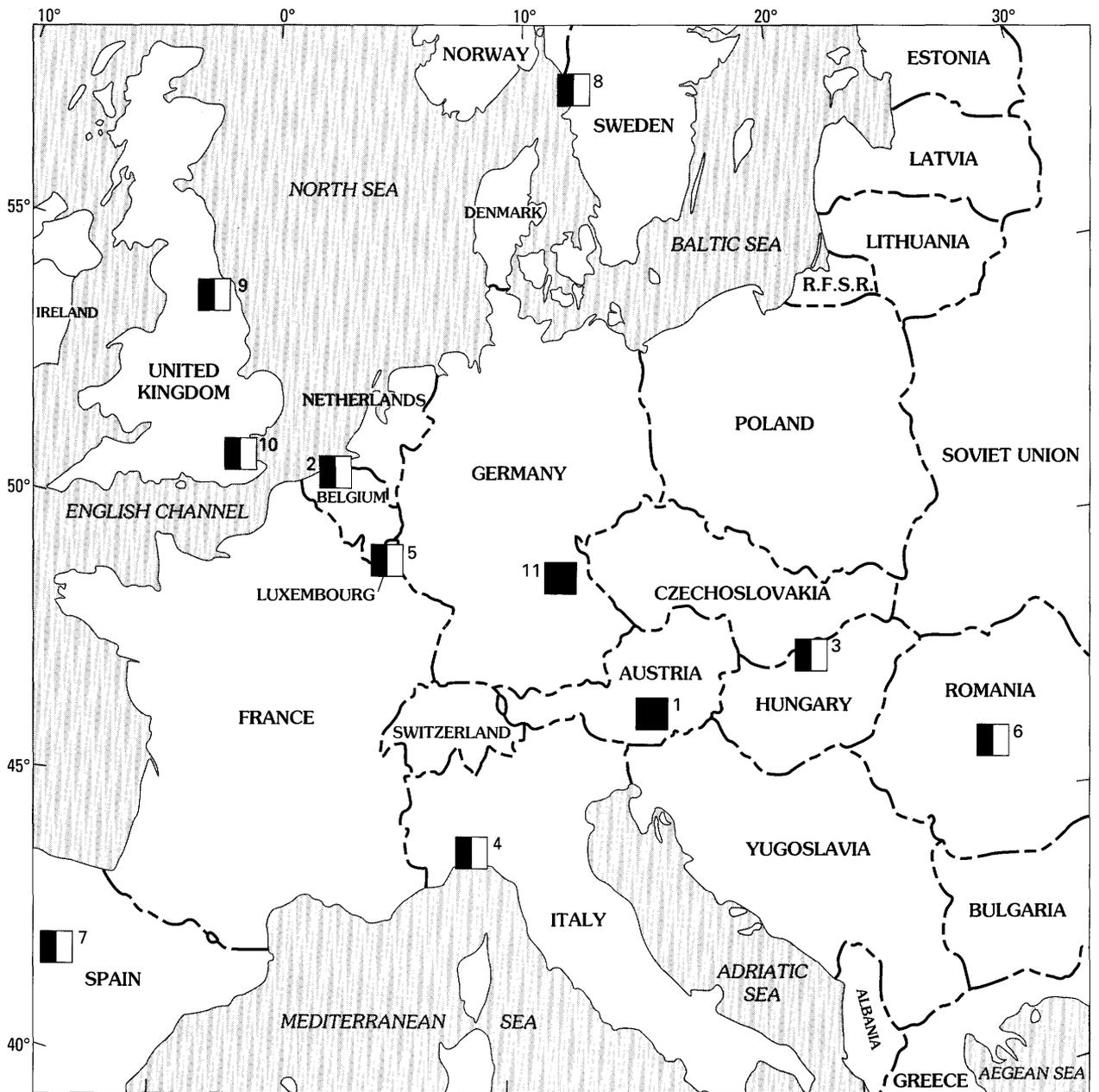


FIGURE 8. Location and products of major vanadium-processing plants in the world. Location names are from tables 8 and 9 in Part II.



EXPLANATION

Ferrovanadium
 Ferrovanadium and vanadium pentoxide



No.	Country	Operation	No.	Country	Operation	No.	Country	Operation
1.	Austria	Treibacher Chemische Werke AG	6.	Romania	Tulcea Metallurgical Complex	9.	United Kingdom	London and Scandinavian Metallurgical Co., Ltd.
2.	Belgium	Sadaci NV	7.	Spain	Ferroastur-Ferroaleaciones Especiales Asturianas	10.		Murex Ltd.
3.	Hungary	Otvózetgyar Salgótarjan	8.	Sweden	MPT-Metals and Powders Trollhättan	11.	Germany	GfE-Gesellschaft für Elektrometallurgie m.b.H.
4.	Italy	Salem-SpA Leghe e Metalli						
5.	Luxembourg	Continental Alloys S.A.						

FIGURE 9. Location and products of major vanadium-processing plants in Europe. Location names are from tables 8 and 9 in Part II.

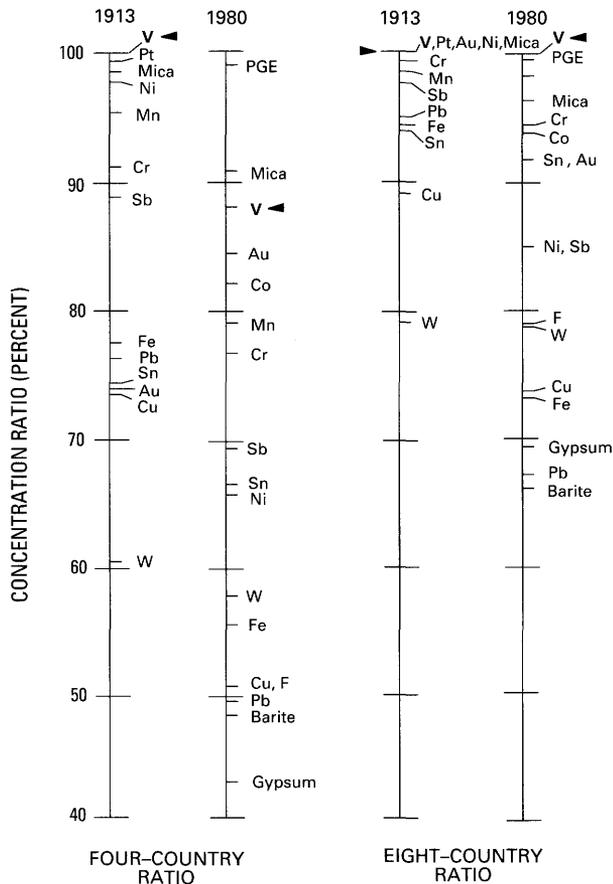
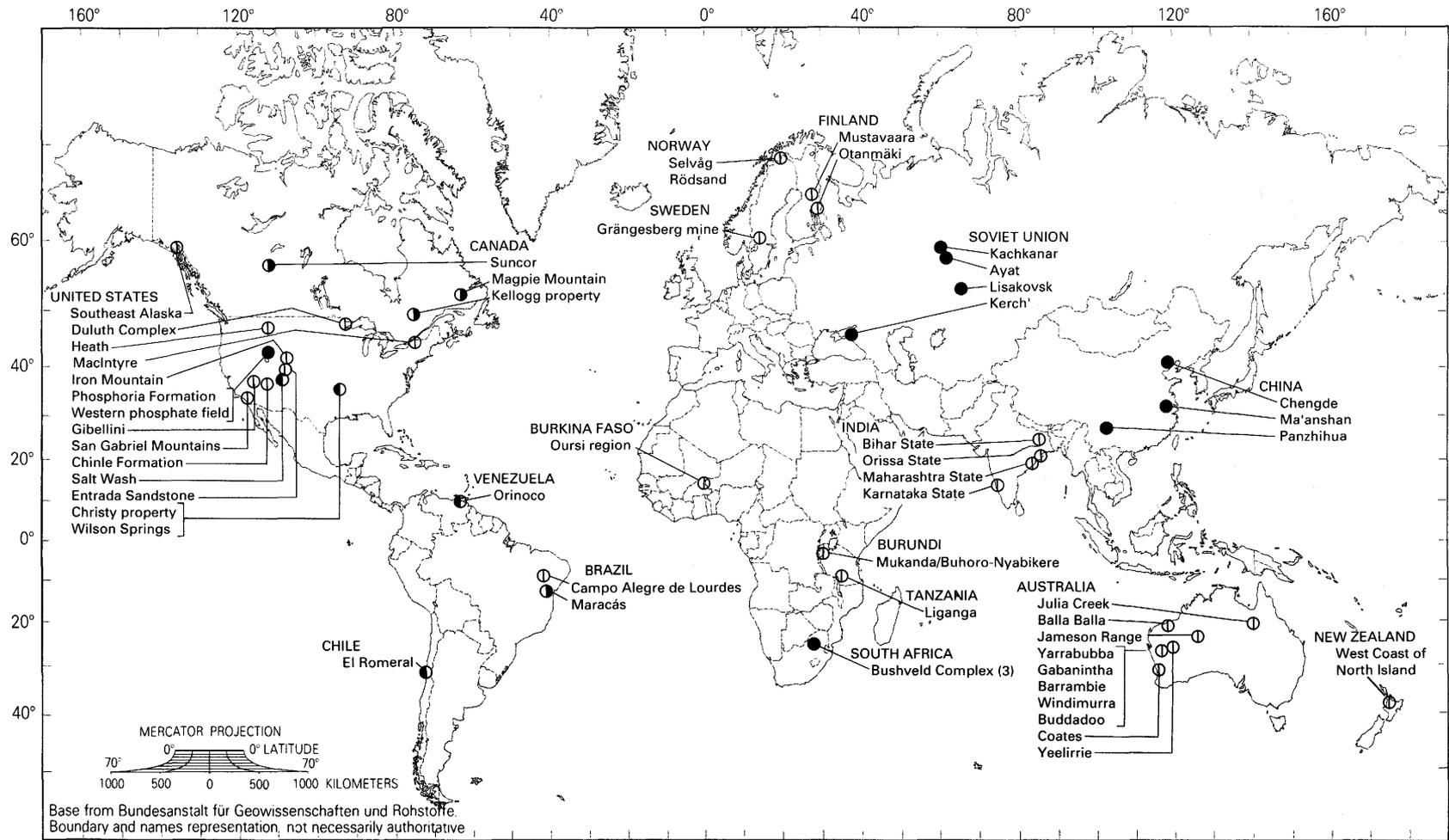


FIGURE 10. Four- and eight-country concentration ratios for selected nonfuel mineral commodity production in 1913 and 1980. The ratios are percent of total world production for the indicated commodities, designated by chemical-element symbols (PGE for platinum-group elements), for the four or eight countries having 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).

World mine production from countries having major deposits was 30,400 metric tons in 1988. About 57 percent of this total originated in South Africa, 29 percent in the Soviet Union, and the balance divided between China and the United States. Present (1990) major primary production is confined to only those four countries and is likely to remain so for many years. A resumption of production is likely in Australia, winning of vanadium from Venezuelan oil is apt to increase, and production from New Zealand iron ores is also a possibility. However, the combined total likely from these sources, approximating 10 percent of current world production, will remain relatively small.



EXPLANATION

- Producer in 1986; probably a significant producer in 2020
- ⊙ Producer in 1986; probably an insignificant producer or exhausted by 2020
- ⊖ No production in 1986; probably a significant producer in 2020
- ⊕ No production in 1986; probably an insignificant producer or no production in 2020

FIGURE 11. Major vanadium deposits and districts, their present production status, and their probable production status in 2020. Number in parentheses (following Bushveld Complex) indicates number of records (deposits and districts). Location names are from tables 6 and 7 in Part II.

PART II—SELECTED INVENTORY INFORMATION FOR VANADIUM DEPOSITS AND DISTRICTS

Tables 6 and 7 contain information from the International Strategic Minerals Inventory records forms for vanadium deposits and districts. Only selected items of information about the location and geology (table 6) and mineral production and resources (table 7) of the deposits are listed here; some of this information has been abbreviated. However, only vanadium deposits that have resources in excess of 10,000 metric tons of contained vanadium metal are included in the inventory. Past producers and selected small deposits are listed separately in table 1 of Part I.

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 records forms have been used in these tables; they are explained in the headnotes.

Tables 8 and 9 contain information on the world's vanadium-producing facilities (Hilliard, 1989). Selected information on plants that produce vanadium pentoxide (table 8) and ferrovandium (table 9) was made available by the participating agencies.

TABLE 6.—Selected geologic and location information

Age abbreviations and prefixes:

Cenozoic	CEN	Permian	PERM
Holocene	HOLO	Mississippian	MISS
Pleistocene	PLEIS	Devonian	DEV
Tertiary	TERT	Precambrian	PREC
Mesozoic	MES	Proterozoic	PROT
Cretaceous	CRET	Archean	ARCH
Jurassic	JUR	Early	E
Triassic	TRI	Middle	M
Paleozoic	PAL	Late	L

Other abbreviation: —, not reported on the ISMI record form.

Site name	Latitude	Longitude	Deposit type	Host rock	Age of mineralization
AUSTRALIA					
Balla Balla (Western Australia).	20°48' S.	117°47' E.	Magmatic	Metagabbro	ARCH
Barrambie (Western Australia).	27°26' S.	119°07' E.	Magmatic, stratiform, massive.	Titaniferous anorthosite to gabbro	.....do.....
Buddadoo (Western Australia).	28°42' S.	116°29' E.	Magmatic	Gabbro	.....do.....
Coates (Western Australia)	31°45' S.	116°23' E.	Magmatic, stratiform disseminated.	Magnetite-rich gabbro, laterite	.....do.....
Gabanintha (Western Australia).	26°56' S.	118°38' E.	Magmatic, stratiform massive.	Anorthositic gabbro	.....do.....
Jameson Range (Western Australia).	25°49' S.	127°41' E.	Magmatic	Gabbro	PROT
Julia Creek (Queensland)	20°28' S.	141°49' E.	Syngenetic, sediment hosted (carbon rich).	Oil shale	ECRET
Windimurra (Western Australia).	28°23' S.	118°33' E.	Magmatic	Gabbro	ARCH
Yarrabubba (Western Australia).	27°02' S.	118°41' E.	Magmatic, stratiform, massive.	Anorthositic gabbro	.....do.....
Yeelirrie (Western Australia)	27°11' S.	119°54' E.	Surficial	Calcrete	TERT
BRAZIL					
Campo Alegre de Lourdes (Bahia).	09°30' S.	43°05' W.	Magmatic	—	—
Maracás (Bahia)	13°22' S.	40°18' W.	.....do.....	—	—

from ISMI records for vanadium deposits and districts

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

ACNL Actinolite	CMST Chamosite	KLNT Kaolinite	PNLD Pentlandite
ALBT Albite	CRBN Carbonate	LBRD Labradorite	PRXN Pyroxene
AMPB Amphibole	CRNT Carnotite	LCNX Leucoxene	PYRT Pyrite
APTT Apatite	DLMT Dolomite	LMON Limonite	PYTT Pyrrhotite
ARPR Arsenopyrite	DPSD Diopside	MGMT Maghemite	QRTZ Quartz
AUGT Augite	EPDT Epidote	MGNT Magnetite	RUTL Rutile
BOTT Biotite	FLDP Feldspar	MMRL Montmorillonite	SDRT Siderite
CFAP Calcium fluorapatite	FRSR Forsterite	MRCS Marcasite	SNDN Sanidine
CLAY Clay	GRNT Garnet	MRTT Martite	SPHN Sphene
CLCD Chalcedony	GTHT Goethite	OLGC Oligoclase	SPNL Spinel
CLCP Chalcopyrite	HBLD Hornblende	OLVN Olivine	SRCT Sericite
CLCT Calcite	HMTT Hematite	ORCL Orthoclase	ULVP Ulvospinel
CLRT Chlorite	ILMN Ilmenite	PLGC Plagioclase	ZOST Zoisite
CLZS Clinzoisite			

Tectonic setting	Local environment	Principal mineral assemblages	Comments	Reference
AUSTRALIA—Continued				
ARCH shield	Magmatic intrusion	MGNT, ILMN, FLDP, SPHN	Three main deposits in metagabbro sequence, two smaller deposits as magnetite bands in leucogabbro.	Baxter (1978).
....do.....	Anorthosite-gabbro complex.	MRTT, ILMN, LCXN, GTHT	Sill-like intrusion in Archean metasediments.	Ward (1975).
....do.....	Magmatic intrusion	MRTT, ALBT, EPDT, OLGC, AMPB	Lenses of vanadiferous titaniferous magnetite in gabbro.	Baxter (1978).
....do.....	Magnetite-gabbro intrusion in granitic rock.	MGNT, ILMN, LBRD, HBLD	Intrusion consists of three gabbroic layers. Vanadium is contained in magnetite-rich layer and in laterite capping.	Do.
....do.....	Anorthositic gabbroic intrusion in Archean succession.	MGNT, ILMN, FLDP, LCXN	Three main bands in magnetite-rich zone. Extensively faulted resulting in 8 areas containing 20 isolated lenses.	Do.
PREC crystalline basement.	Mafic and ultramafic intrusive.	MGNT, ILMN, FLDP, OLVN, PRXN	Bands of titaniferous magnetite in gabbro.	Do.
Marine basin	Shallow estuarine mudflat with deeper channels.	—	Two oil-shale horizons within limestone and siltstone.	PACMINEX (Pty.) Ltd. (1976).
ARCH shield	Magmatic intrusion	MGNT, ILMN, FLDP	Magnetite is a major component of gabbro and dolerite layers.	Baxter (1978).
....do.....	Anorthositic-gabbroic intrusion in Archean succession.	MGNT, ILMN, FLDP	Titaniferous magnetite band, 2-km strike, 1.3 m thick.	Do.
....do.....	Valley-fill calcrete	CRNT, DLMT, CLCT, QRTZ, CLAY	Carnotite is present in calcrete (principal host rock) and in clay-quartz horizon.	Western Mining Corp. (1978).
BRAZIL—Continued				
—	—	MGNT	—	Duke (1983).
—	—	MGNT	—	Bureau de Recherches Géologiques et Minières (1985).

TABLE 6.—Selected geologic and location information

Site name	Latitude	Longitude	Deposit type	Host rock	Age of mineralization
BURKINA FASO					
Oursi region	14°35' N.	00°30' W.	Magmatic	Gabbro, ophiolitic series, volcano-sediments, granite.	PREC
BURUNDI					
Mukanda/Buhoro-Nyabikere (Kibara-Burundi-Karagwe-Ankole metallogenic zone).	03°24' S.	30°00' E.	Magmatic	Titanomagnetite in gabbroic massif	—
CANADA					
Kellogg property (Quebec)	49°49' N.	74°00' W.	Magmatic, stratiform	Metaferro-pyroxenite; gabbro	ARCH
Magpie Mountain (Quebec)	51°23' N.	64°04' W.	Magmatic, nonstratiform	Gabbroic anorthosite	PROT
Suncor (Alberta)	57°00' N.	111°29' W.	Syngenetic sediment hosted (carbon rich).	Sandstone with shale layers and clay lenses.	LCRET
CHILE					
El Romeral (Coquimbo)	29°42' S.	71°15' W.	Magmatic	Andesite porphyry	LCRET
CHINA					
Chengde (Hebei)	40°46' N.	118°11' E.	Magmatic	—	—
Ma'anshan (Washan) (Anhui Province).	31°47' N.	118°35' E.	Epigenetic	—	—
Panzhihua (Sichuan Province).	27°18' N.	101°58' E.	Magmatic	—	—
FINLAND					
Mustavaara (Northern Finland).	65°47' N.	27°59' E.	Magmatic	Anorthosite	PREC
Otanmäki (Middle Finland)	64°15' N.	28°10' E.	.....do.....	Amphibolite, anorthosite, and gabbro	MPREC
INDIA					
Bihar State	25°13' N.	85°31' E.	Magmatic	—	—
Karnataka State	13°18' N.	75°18' E.	.....do.....	Gabbro to anorthosite	PREC
Maharashtra State	21°08' N.	79°41' E.	.....do.....	—	—
Orissa State	21°49' N.	86°23' E.	.....do.....	—	—
NEW ZEALAND					
West Coast of North Island	36°39' S. to 39°48' S.	174°20' E. to 174°35' E.	Syngenetic, sediment hosted (noncarbonaceous).	Titaniferous magnetite in beach sands.	PLEIS-HOLO
NORWAY					
Rödsand (Møre og Romsdal)	62°48' N.	08°10' E.	Magmatic	Metabasite	PREC
Selvåg (Lofoten Islands, Nordland).	68°46' N.	14°35' E.	.....do.....	Gneiss, syenite, gabbro, anorthosite	—

from ISMI records for vanadium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	Reference
BURKINA FASO—Continued				
PREC shield	—	MGNT, ILMN, PYTT, PNLD, ARPR	Ten significant magnetite deposits. Magnetite concentration is in gabbros.	Neybergh and others (1980).
BURUNDI—Continued				
—	—	MGNT	—	Mining Annual Review (1983).
CANADA—Continued				
ARCH volcanic greenstone belt.	Subvolcanic layered anorthosite-gabbro sill.	V- and Ti-rich MGNT; ILMN, PRXN AMPB, PLGC, OLVN, PYRT, CLRT, CRBN, LMON, GTHT, ZOST, EPDT, SPHN.	Three magnetite-rich zones as discontinuous layered magmatic segregations.	Rose (1969).
PROT orogenic belt.	Oxide-rich gabbroic anorthosite.	Ti- and V-rich MGNT, ILMN, SPNL, PLGC, PRXN, BOTT.	Massive or interbanded titaniferous magnetite.	Vallée and Raby (1971), Rose (1969).
—	—	—	—	Rose (1973).
CHILE—Continued				
MES-CEN mobile belt; Atacama fault system.	Romeral fault	MGNT, HMTT, ACNL, PLGC, DPSD, CLZS, SPHN, CI-APTT.	—	Schmidt and others (1981).
CHINA—Continued				
—	—	MGNT	—	Chin (1982).
—	—	MGNT, HMTT	—	Do.
—	—	V-bearing MGNT, ILMN; sulphates and silicates.	—	World Mining (1980).
FINLAND—Continued				
—	—	MGNT, PLGC, AUGT, HBLD	Disseminated and tabular deposit.	Busch (1977).
PREC shield	—	MGNT, ILMN, PYRT, AMPB, PLGC	The deposit is compound of a large number of small lenticular ore lenses.	Do.
INDIA—Continued				
—	—	MGNT	—	Fortnightly Journal of Industry and Commerce Review (1979).
Platform, miogeosynclinal.	Dharwar greenstone belts	MGNT; ILMN, ULVP, MGMT, MRTT, CLCP, PYTT.	—	Vasudev and Srinivasan (1979).
—	—	MGNT	—	Fortnightly Journal of Industry and Commerce Review (1979).
—	—	MGNT	—	Do.
NEW ZEALAND—Continued				
Platform	—	MGNT	—	New Zealand Geological Survey (1981).
NORWAY—Continued				
PAL mobile belt	—	MGNT, ILMN, HMTT, PYRT, PYTT, CLCP.	Horizontal ore section of 20,000 m ² .	Svinndal (1976).
—	—	MGNT, ILMN, SPNL, PYTT, MRCS, PYRT.	—	Geis (1971).

TABLE 6.—Selected geologic and location information

Site name	Latitude	Longitude	Deposit type	Host rock	Age of mineralization
SOUTH AFRICA					
Bushveld Complex—eastern section (Transvaal, Lebowa).	25°10' S.	29°55' E.	Magmatic, stratiform, massive.	Vanadiferous magnetite in gabbroic layered intrusion.	MPREC
Bushveld Complex—northern section (Transvaal, Lebowa).	23°55' S.	28°47' E.	.....do.....	.....do.....	.....do.....
Bushveld Complex—western section (Transvaal, Bophuthatswana).	25°27' S.	27°21' E.	.....do.....	.....do.....	.....do.....
SOVIET UNION					
Ayat (Ural Mountains)	57°03' N.	60°15' E.	Syngenetic, sediment hosted (non-carbonaceous).	Phosphorus-rich brown ironstone	—
Kachkanar (Ural Mountains)	58°40' N.	59°29' E.	Magmatic	Gabbro, pyroxenite	DEV-PERM
Kerch' (Crimea)	45°22' N.	36°26' E.	Syngenetic, sediment hosted (non-carbonaceous).	Phosphorous oolitic brown ironstone	—
Lisakovsk (Ural Mountains)	52°40' N.	64°30' E.	.....do.....	.....do.....	—
SWEDEN					
Grängesberg mine (central Sweden).	60°05' N.	14°57' E.	Magmatic	Gneiss, pegmatite, and dacite-andesite dikes.	PREC
TANZANIA					
Liganga (Njombe district)	09°50' S.	34°52' E.	Magmatic	Anorthosite to gabbro	PREC
UNITED STATES					
Chinle Formation (Utah, Arizona).	36°56' N.	109°53' W.	Epigenetic	Sandstone	TRI
Christy Property (Arkansas)	34°28' N.	92°51' W.	.....do.....	Novaculite and argillite	LCRET
Duluth Complex (Minnesota)	47°30' N.	91°30' W.	Magmatic	Titaniferous magnetite	MPROT
Entrada Sandstone (Colorado).	39°40' N.	107°41' W.	Epigenetic	Sandstone	—
Gibellini (Nevada)	39°12' N.	116°06' W.	Syngenetic, sediment hosted (carbon rich).	Siltstone and shale	DEV
Heath (Montana)	46°30' N.	110°00' W.	.....do.....	Black shale	LMISS
Iron Mountain (Wyoming)	41°36' N.	105°20' W.	Magmatic	Massive titaniferous magnetite in anorthosite.	PREC
MacIntyre (New York)	44°03' N.	74°03' W.	.....do.....	Titaniferous magnetite	—
Phosphoria Formation (Idaho).	42°39' N.	111°36' W.	Syngenetic, sediment hosted (carbon rich).	Black shale and phosphatic shale	PERM

from ISMI records for vanadium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	Reference
SOUTH AFRICA—Continued				
Intracratonic	Magnetite seam(s) in layered sequence of Bushveld Complex.	MGNT	Main magnetite seam, strike at least 130 km, average thickness 2.0 m, 1.5–1.75 percent V ₂ O ₅ .	MacCaskie (1984).
.....do.....	.....do.....	MGNT	One to two magnetite-rich seams at least 100 km long, and 5–20 m thick, with 1.4–1.9 percent V ₂ O ₅ .	Do.
.....do.....	.....do.....	MGNT	One to three magnetite seams, strike at least 115 km, 1–2 m thick. Vanadiferous magnetite-rich zones 10–30 m thick; localized V ₂ O ₅ is 1.2–2.2 percent in individual seams.	Do.
SOVIET UNION—Continued				
—	—	HMTT, LMON (GTHT), MGNT, SDRT, CMST.	—	Sokoloff (1963).
PAL mobile belt	—	MGNT, HMTT, CLCP, AMPB, PRXN	—	Zitzmann (1976).
—	—	HMTT, LMON (GTHT), MGNT, SDRT, CMST.	—	Stanton (1972).
—	—	HMTT, LMON (GTHT), MGNT, SDRT, CMST.	—	Do.
SWEDEN—Continued				
PREC shield	—	MGNT, HMTT, APTT, QRTZ, ACNL, BOTT.	—	Metal Bulletin (1977).
TANZANIA—Continued				
—	—	MGNT, ILMN, SPNL, CLRT	Four lenticular, elongated, and dikelike ore bodies.	United Nations, Department of Economic and Social Affairs (1970).
UNITED STATES—Continued				
Craton	Fluvial and fluviolacustrine.	U-oxides;V-clays; V-oxides	Deposits are predominantly in paleochannels.	Wood (1968).
Stable platform	—	QRTZ, MMRL, GTHT, RUTL	Ore is confined to a shaly unit within novaculite.	Stone and others. (1982).
Craton	Stratified gabbro	MGNT, ILMN, PLGC,AUGT, OLVN	Magnetite as high-grade segregations and disseminated in gabbroic rocks.	Groutt (1950).
.....do.....	—	V-clays;V-micas; V-oxides	Ore in peneconcordant layers in sandstone.	Fischer (1942).
Inner arc basin	—	CLAY, QRTZ, CLRT,APTT	—	Desborough and others (1979).
Cratonic platform embayment.	Black shale facies	CLAY, QRTZ, CLCT	Metalliferous carbon-rich shales in limestone and mudstone.	Desborough and others (1981).
Craton	Intrusive mafic complex	MGNT, ILMN, SPNL, OLVN, APTT, BOTT, FLDP, FRSR.	Titaniferous magnetite occurs in numerous dikelike bodies.	Pinnel and March (1954).
.....do.....	—	MGNT, ILMN, PLGC, HBLD, PRXN, GRNT.	Massive magnetite-rich lenses in anorthosite and bands in gabbro.	Force and Lynd (1984).
Shallow marine	Shelf facies	QRTZ, CLAY, APTT, organic matter	Vanadium in shale associated with organic material 1–2 m thick.	Love (1967).

TABLE 6.—Selected geologic and location information

Site name	Latitude	Longitude	Deposit type	Host rock	Age of mineralization
UNITED STATES—Continued					
Salt Wash (Arizona, Colorado, Utah, New Mexico).	37°56' N.	109°02' W.	Epigenetic	Sandstone	LJUR
San Gabriel Mountains (California).	34°22' N.	118°15' W.	Magmatic	Gabbro	PREC
Southeast Alaska (Alaska)	59°27' N.	135°54' W.	.....do.....	Ultramafics	CRET
Western U.S. phosphate field (Idaho, Utah, Wyoming).	42°39' N.	111°36' W.	Syngenetic, sediment hosted (carbon rich).	Phosphorite	PERM
Wilson Springs (Arkansas)	34°29' N.	92°58' W.	Epigenetic	Foyaite, novaculite, and argillite	LCRET
VENEZUELA					
Orinoco	10°19' N.	63°08' W.	Syngenetic, sediment hosted (carbon rich).	Tar sand (bitumen-impregnated sandstone).	—

from ISMI records for vanadium deposits and districts—Continued

Tectonic setting	Local environment	Principal mineral assemblages	Comments	Reference
UNITED STATES—Continued				
Craton	Fluviolacustrine plain	V-oxides, V-clays, V-chlorites, V-micas	—	Fischer (1942).
Craton	Stratified mafic pluton	MGNT, ILMN, AUGT, PLGC	—	Carter (1982a,b).
Magmatic arc	Zoned ultramafic intrusives	MGNT	Vanadiferous titanomagnetite segregations in zoned ultramafic intrusions.	Kennedy and Walton (1946).
Shallow marine	Shelf facies	CFAP, QRTZ, CLCD, ORCL, SRCT, LLNT, MMRL, DLMT, LMON, PYRT.	Vanadium associated with organic material.	Fantel and others (1983).
Stable platform	Intrusive wall rock contact	QRTZ, MMRL, GTHT, PRXN, SNDN	Vanadiferous clays concentrated along fenitized zone.	Hollingsworth (1967).
VENEZUELA—Continued				
—	—	—	Vanadium in crude oil obtained from oil shales.	Mining Annual Review (1981).

TABLE 7.—Selected production and mineral-resource information

Abbreviations used throughout this table:

—, not reported on the ISMI record form; t, metric tons.

Mining method abbreviations: S, surface; U, underground; N, not yet producing.

Annual production includes some or all of the following items (separated by semicolons): annual production in thousand metric tons of material mined (unless other processing stage is indicated); grade of reported material; and year of production (or range of years used to estimate average annual production).

Site name	Year of discovery	Year of first production	Mining method	Commodities
AUSTRALIA				
Balla Balla (Western Australia)	1961	—	S	V, Ti
Barrambie (Western Australia)	1960	—	N	Fe, Ti, V
Buddadoo (Western Australia)	1973	—	—	V, Ti
Coates (Western Australia)	1961	1981	N	V
Gabanintha (Western Australia)	1903	—	N	V, Ti
Jameson Range (Western Australia)	1966	—	—	V, Ti
Julia Creek (Queensland)	1966	—	N	Oil, V
Windimurra (Western Australia)	1960	—	—	V, Ti
Yarrabubba (Western Australia)	1960	—	N	V, Ti
Yeelirrie (Western Australia)	1971	—	N	U, V
BRAZIL				
Campo Alegre de Lourdes (Bahia)	—	—	N	Ti, V, Fe
Maracás (Bahia)	—	—	N	V
BURKINA FASO				
Oursi Region	—	—	—	Fe, V, Ti
BURUNDI				
Mukanda/Buhoro Nyabikere (Kibara-Burundi-Karagwe-Ankole metallogenic zone).	—	—	N	V, Ni
CANADA				
Kellogg property (Quebec)	1954	—	N	Fe, Ti, V
Magpie Mountain (Quebec)	1953	—	N	Fe, Ti, V, Cr
Suncor (Alberta)	1778	—	S	C, S, V
CHILE				
El Romeral (Coquimbo)	1903	1955	S	Fe, V, Ti

from ISMI records for vanadium deposits and districts

Cumulative production includes some or all of the following items (separated by semicolons): cumulative production in thousand metric tons of material (unless other processing stage is indicated); grade of reported material; and years for reported cumulative production.

Resources include, for various resource categories, some or all of the following items (separated by semicolons): resource in thousand metric tons; U.N. resource classification (United Nations Economic and Social Council, 1979; Schanz, 1980); grade (unless resource is specified as contained metal); and year of estimate. Grades reported for mining properties often are the grade of mill feed, while for undeveloped properties, *in situ* grades are usually reported. Dilution in the mill feed grades may be about 5 percent for open-pit mining and 15 percent for underground mining.

Annual production (in 1,000 t)	Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
AUSTRALIA—Continued			
—	—	1,900; R1M; 0.75 percent V ₂ O ₅ ; 1961. 150,000; R2S; 0.75 percent V ₂ O ₅ ; 1966.	Low potential for early development.
—	—	33,844; R1M; 0.48 percent V ₂ O ₅ ; 1984. 415,000; R2S; 0.46 percent V ₂ O ₅ ; 1972.	No production plans to date. Exploration and feasibility studies continuing.
—	—	20,000–25,000; R2S; 0.7 percent V ₂ O ₅ .	Potential for mining is lower than that of most other resources elsewhere in Western Australia. Further exploration required.
27; 1.13 percent V ₂ O ₅ ; 1980–81.	53; 1.13 percent V ₂ O ₅ ; 1980–81.	1,200; R1M; 0.88 percent V ₂ O ₅ ; 1971. 39,000; R1S; 0.51 percent V ₂ O ₅ ; 1971. 5,900–7,000; R2S; 0.55 percent V ₂ O ₅ ; 1971.	Operations suspended in 1981 pending improved plant performance and product price.
—	—	8,560; R1M; 1.24 percent V ₂ O ₅ ; 1961.	Do.
—	—	—	Very large resources, which typically grade 1.1 percent V ₂ O ₅ , but no estimates available.
—	—	3,370,000 (oil shale); R1S; 0.1–0.3 percent V ₂ O ₅ ; 1983.	No firm plans to develop this deposit.
—	—	40,000; R2S; 0.3–0.4 percent V ₂ O ₅ .	A decision to proceed with development is imminent but awaits various mining and environmental approvals and financing arrangements.
—	—	1,980; R2S; 1.3 percent V ₂ O ₅ ; 1961.	Potential lower than other V resources in Western Australia.
—	—	12,150; r1E; 0.08 percent V ₂ O ₅ ; 1978. 14,750; r1M; 0.03 percent V ₂ O ₅ ; 1978. 6,910; R1M; Less than 0.03 percent V ₂ O ₅ ; 1978.	Recoverable resources (r) as byproduct of uranium.
BRAZIL—Continued			
—	—	110,000; R2S; 0.75 percent V ₂ O ₅ .	Poor infrastructure, unlikely that the V deposits will be developed in future.
—	—	3,000; R1E; 1.4 percent V ₂ O ₅ .	Could easily be exploited because of available infrastructure.
BURKINA FASO—Continued			
—	—	60,000; R1S; 0.60 percent V ₂ O ₅ .	Exploitation depends on the construction of a 350-km railway line.
BURUNDI—Continued			
—	—	5,500; R1S; 1.5 percent V ₂ O ₅ .	—
CANADA—Continued			
—	—	73,440; R1S+R2S; 0.50 percent V ₂ O ₅ ; 1975.	Pilot tests yielded magnetic concentrates with 1.4 percent V ₂ O ₅ , 62 percent Fe, and 9.3 percent TiO ₂ . May have potential if demand and processing of titanium are improved.
—	—	276,889; R1S; 0.19 percent V ₂ O ₅ ; 1973. 846,887; R2S; 0.19 percent V ₂ O ₅ ; 1973.	Recovery of V would require chemical extraction.
—	—	20 (fly ash); R1M; 3.5 percent V ₂ O ₅ .	V ₂ O ₅ recovered from fly ash from Suncor from mid-1990 to the spring of 1991.
CHILE—Continued			
—	7; 1950–84	77,216; R1E; 0.54–0.71 percent V ₂ O ₅ ; 1986. 84,836; R1M; 0.54–0.71 percent V ₂ O ₅ ; 1986.	—

TABLE 7.—Selected production and mineral-resource information

Site name	Year of discovery	Year of first production	Mining method	Commodities
CHINA				
Chengde (Hebei)	—	—	—	Ti, V
Ma'anshan (Washan) (Anhui Province)	—	1965	S	Fe, V
Panzhihua (Sichuan Province)	1939	1977(?)	S	Ti, V, Fe, Ni, Co, Cr, Ga
FINLAND				
Mustavaara (Northern Finland)	1967	1976	S	V, Ti, Fe
Otanmäki (Middle Finland)	1937	1953	U	Fe, V, Ti
INDIA				
Bihar State	—	—	N	V
Karnataka State	—	—	N	V
Maharashtra State	—	—	N	V
Orissa State	—	—	—	V
NEW ZEALAND				
West Coast of North Island	—	—	—	Fe, Ti, V
NORWAY				
Rödsand (Møre og Romsdal)	About 1850	1899	U	Fe, V, Ti
Selvåg (Lofoten Islands, Nordland)	—	—	N	V, Fe, Ti
SOUTH AFRICA				
Bushveld Complex—eastern section (Transvaal, Lebowa).	1943	1968	S	Fe, V
Bushveld Complex—northern section (Transvaal, Lebowa).	1943	—	—	Fe, V
Bushveld Complex—western section (Transvaal, Bophuthatswana).	1943	1968	S	Fe, V
SOVIET UNION				
Ayat (Ural Mountains)	1945	—	—	Fe, V
Kachkanar (Ural Mountains)	—	1898	S	Fe, V, Ti
Kerch' (Crimea)	—	—	—	Fe, V
Lisakovsk (Ural Mountains)	—	—	—	Fe, V
SWEDEN				
Grängesberg mine (central Sweden)	—	16th century.	U, S	Fe, P, V
TANZANIA				
Liganga (Njombe district)	—	—	N	Fe, Ti, V
UNITED STATES				
Chinle Formation (Utah, Arizona)	Pre-1904	—	N	U, V, Mo, Cu
Christy property (Arkansas)	1943	1984	S	V, Ti
Duluth Complex (Minnesota)	1870	—	N	Ti, V
Entrada Sandstone (Colorado)	1900	1909	N	U, V

from ISMI records for vanadium deposits and districts—Continued

Annual production (in 1,000 t)	Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
CHINA—Continued			
—	—	85,000; R1E; 0.35 percent V ₂ O ₅ .	China's second largest source of V.
—	—	400,000; R1E; 0.21 percent V ₂ O ₅ .	China's third largest producer.
—	—	1,050,000; R1E; 0.3 percent V ₂ O ₅ . 5,000,000; R2E; 0.3 percent V ₂ O ₅ .	Constitutes 80 percent of China's known V resources and is its largest producer. Plans to increase the production of ilmenite concentrate exist.
FINLAND—Continued			
—	—	40,000; R1M; 0.36 percent V ₂ O ₅ . 40,000; R1S; 0.36 percent V ₂ O ₅ .	Past producer.
—	—	20,000; R1M; 0.25 percent V ₂ O ₅ ; 1975.	—
INDIA—Continued			
—	—	1,118; R2S; 1.65 percent V ₂ O ₅ .	—
—	—	7,631; R2S; 0.37–0.82 percent V ₂ O ₅ .	—
—	—	6,200; R2S; 0.88–1.16 percent V ₂ O ₅ .	—
—	—	7,000; R1S; 0.8–1.2 percent V ₂ O ₅ .	—
NEW ZEALAND—Continued			
—	—	650,000 (concentrate); R1S+R2S; 0.36–0.40 percent V ₂ O ₅ .	—
NORWAY—Continued			
—	—	28; R1E; 100 percent V metal.	Past producer.
—	—	17,600; R1M; 0.5 percent V ₂ O ₅ .	—
—	—	20,000; R1S+R2S; 0.20 percent V ₂ O ₅ .	—
SOUTH AFRICA—Continued			
—	—	132,160; R1E; 1.65 percent V ₂ O ₅ . 45,480; R1M; 1.66 percent V ₂ O ₅ . 1,296,880; R1S; 0.83 percent V ₂ O ₅ . 10,910; R2E; 1.70 percent V ₂ O ₅ . 1,540,570; R2S; 0.30 percent V ₂ O ₅ .	Resource estimates are taken from MacCaskie, 1984.
—	—	126,000; R1E; 1.67 percent V ₂ O ₅ . 421,000; R1M; 1.73 percent V ₂ O ₅ . 1,748,000; R2E; 1.73 percent V ₂ O ₅ . 321,000; R2S; 1.67 percent V ₂ O ₅ .	Do.
—	—	61,450; R1E; 1.49 percent V ₂ O ₅ . 17,750; R1M; 2.04 percent V ₂ O ₅ . 392,624; R1S; 1.60 percent V ₂ O ₅ . 62,700; R2S; 1.6 percent V ₂ O ₅ .	Do.
SOVIET UNION—Continued			
—	—	(Included with Lisakovsk deposit)	—
—	—	6,100,000; R1E+R2E; 0.15 percent V ₂ O ₅ .	Largest source of V in the Soviet Union.
—	—	(Included with Lisakovsk deposit)	—
—	—	3,000,000; R1E; 0.1 percent V ₂ O ₅ . (total resources for Lisakovsk, Kerch', and Ayat).	—
SWEDEN—Continued			
—	—	150,000; R1S; 0.14 percent V ₂ O ₅ .	No V production. Grade of V low.
TANZANIA—Continued			
—	—	78,000; R1S; 0.6 percent V ₂ O ₅ .	Potential producer.
UNITED STATES—Continued			
—	—	352.6; R2S; 0.58 percent V ₂ O ₅ ; 1985.	Economic viability depends on associated U ₃ O ₈ production.
—	—	3,000; R1S; 1.0 percent V ₂ O ₅ ; 1976.	Current producer of V.
—	—	23,000; R2S; 0.5 percent V ₂ O ₅ ; 1950.	A possible major titanium resource with vanadium as byproduct. No production planned.
—	—	907; R1S; 1.25–1.75 percent V ₂ O ₅ ; 1961. 6,176; R2S; 1.24 percent V ₂ O ₅ ; 1984.	No further announced production plans.

TABLE 7.—Selected production and mineral-resource information

Site name	Year of discovery	Year of first production	Mining method	Commodities
UNITED STATES—Continued				
Gibellini (Nevada)	Pre-1960	—	N	V
Heath (Montana)	—	—	N	Oil, V, Ni, Zn
Iron Mountain (Wyoming)	1850	—	N	Ti, Fe, V
MacIntyre (New York)	1826	1942	S	Ti, Fe, V
Phosphoria Formation (Idaho)	—	—	N	V
Salt Wash (Arizona, Colorado, New Mexico, Utah).	1899	About 1900	U, S	U, V, Mo
San Gabriel Mountains (California)	Early 1900's	—	N	Ti, V, Fe
Southeast Alaska (Alaska)	1946	—	N	Fe, Ti, V
Western U.S. phosphate field (Idaho, Utah, Wyoming).	1940	—	S	
Wilson Springs (Arkansas)	1960	1966	N	V
VENEZUELA				
Orinoco	—	—	—	Oil, V, Ni

from ISMI records for vanadium deposits and districts—Continued

Annual production (in 1,000 t)	Cumulative production (in 1,000 t)	Resources (in 1,000 t)	Comments
UNITED STATES—Continued			
—	—	22,000; R1S; 0.2–0.7 percent V ₂ O ₅ ; 1983.	Small, low grade and uneconomic.
—	—	22,860; R2S; 0.7 percent V ₂ O ₅ ; 1974.	
—	—	17,284; R2S; 0.81 percent V ₂ O ₅ .	No production plans announced.
—	—	161,500; R1M; 0.25–0.40 percent V ₂ O ₅ ; 1953, 1961.	Do.
—	—	43,000; R1M; 0.5 percent V ₂ O ₅ ; 1984.	V grade in ilmenite separates probably too low.
—	—	430,300; R2S; 0.7 percent V ₂ O ₅ ; 1985.	Vanadiferous unit 10 meters below phosphatic zone mined. No production planned.
—	—	4,200; R1S; 0.755 percent V ₂ O ₅ ; 1984.	—
—	—	91,500; R2S; 0.31 percent V ₂ O ₅ ; 1984.	
—	—	1,200,000; R2S; 0.07 percent V ₂ O ₅ ; 1982.	—
—	—	1,200; R1E; 0.3 percent V ₂ O ₅ (in concentrate); 1974.	No production plans announced.
—	—	1,400,000; R2S; 0.38 percent V ₂ O ₅ (in concentrate); 1985.	
—	—	4,892,000; R1M; 0.15 percent V ₂ O ₅ ; 1981.	Vanadium is contained in beneficiated phosphorite.
—	—	23,000,000; R2S; 0.143 percent V ₂ O ₅ ; 1985.	
—	—	1,000; R1S; 1.0 percent V ₂ O ₅ ; 1976.	Inconsistent producer during last 5 years.
VENEZUELA—Continued			
—	—	8,640 (oil); r1M; 0.02 percent V ₂ O ₅ .	Recovery of V from oil residues and fly ash only at very few installations in the world.
—	—	90 (oil); r1E.	

TABLE 8.—Selected production information for vanadium pentoxide

[—, not reported; t, metric tons]

Producer	Latitude	Longitude	Plant type	Feed	Process	Annual capacity (metric tons)	Comments
AUSTRIA							
Treibacher Chemische Werke AG, Treibach.	46°52' N.	14°28' E.	Mill	Iron slag	Roast-leach	—	—
CANADA							
Carbovan Inc., Fort McMurray, Alberta.	56°40' N.	111°07' W.	Mill	Fly ash	Leach-leach	—	Recovered V ₂ O ₅ from fly ash from Suncor oil sands operation from mid-1990 to the spring of 1991.
CHINA							
Chengde Ferroalloy plant, Chengde, Hebei.	40°59' N.	118°06' E.	Mill	Iron slag	Roast-leach	—	—
China Titanium Corp. Zunyi, Guizhou.	27°41' N.	106°50' E.	.....do.....	.....do.....	.....do.....	—	—
Emei Ferroalloy plant, Emei, Sichuan.	29°35' N.	103°31' E.	.....do.....	.....do.....	.....do.....	—	Total estimated capacity 12,5000 t and reported 7,000 t per year production (1988).
Jinzhou Ferroalloy plant, Jinzhou, Liaoning.	41°07' N.	121°06' E.	.....do.....	.....do.....	.....do.....	—	—
Nanjing Ferroalloy plant, Nanjing, Jiangsu.	32°03' N.	118°47' E.	.....do.....	.....do.....	.....do.....	—	—
Shanghai Metallurgical plant #2, Shanghai.	31°14' N.	121°28' E.	.....do.....	.....do.....	.....do.....	—	—
GERMANY							
GfE-Gesellschaft für Elektrometallurgie m.b.H., Nuremberg.	49°27' N.	11°05' E.	Mill	Iron slag	Roast-leach	—	—
JAPAN							
Shinko Chemical Co., Ltd., Osaka.	35°57' N.	137°17' E.	Mill	Spent catalyst	Leach-leach	227	—
The Taiyo Mining and Industrial Co., Ltd., Ako City, Hyogo Prefecture.	34°40' N.	134°22' E.	.....do.....	.....do.....	.....do.....	454	—
SOUTH AFRICA							
Vantra Division, Highveld Steel and Vanadium Co., Ltd., Witbank.	25°55' S.	29°10' E.	Mill	Iron slag	Roast-leach	7,257	—
Transvaal Alloys Ltd., Wapadskloof, Middleburg, Transvaal.	25°31' S.	30°52' E.	.....do.....	Magnetite	.....do.....	1,633	—
Vametco Minerals Corp., Krokodilkraal, Bophuthatswana.	25°43' S.	27°52' E.	.....do.....	.....do.....	.....do.....	5,443	—
Vansa Vanadium S.A., Ltd., Kennedy's Vale, Steelpoort.	24°50' S.	30°06' E.	.....do.....	.....do.....	Leach-leach	2,722	—
SOVIET UNION							
Kirovabad Alumina plant, Kirovabad, Azerbaijan.	40°39' N.	46°20' E.	—	—	—	—	—
UNITED STATES							
AMAX Metals Recovery, Inc., Braithwaite, Louisiana.	29°51' N.	89°57' W.	Mill	Spent catalyst	Roast-leach	—	Total United States annual capacity estimated at 9,100 t.
Gulf Chemical and Metallurgical, Freeport, Texas.	28°56' N.	95°20' W.	.....do.....	.....do.....	Leach-leach	—	—
Kerr-McGee Chemical Corp., Soda Springs, Idaho.	42°40' N.	111°35' W.	.....do.....	FePO ₄ slag	Roast-leach	—	—

TABLE 8.—*Selected production information for vanadium pentoxide—Continued*

Producer	Latitude	Longitude	Plant type	Feed	Process	Annual capacity (metric tons)	Comments
UNITED STATES—Continued							
Strategic Materials Corp., Hot Springs, Arkansas.	34°30' N.	93°02' W.	.....do.....	Petroleum residue, spent catalyst, fly ash.	Leach-leach	—	—
Umetco Minerals Corp., Blanding, Utah.	37°37' N.	109°29' W.	.....do.....	Carnotite	Solvent extraction.	—	—

TABLE 9. — Selected production information for ferrovandium

[—, not reported]

Producer	Latitude	Longitude	Plant type	Process	Annual capacity (metric tons)	Comments
ARGENTINA						
Pamet S.A. Argentina Cifi, Buenos Aires	34°40' S.	58°30' W.	—	—	—	—
Stein Ferroaleaciones Sacifa, Luján de Cuyo, Mendoza.	33°05' S.	68°53' W.	—	—	—	—
AUSTRIA						
Treibacher Chemische Werke AG, Treibach	46°52' N.	14°28' E.	Converter	Aluminothermic	—	—
BELGIUM						
Sadaci NV Langerbruggekaai plant, Ghent	51°03' N.	03°43' E.	Converter	Aluminothermic	3,000	—
BRAZIL						
Cia Paulista de Ferro Ligas, Barbacena, Minas Gerais.	21°13' S.	43°47' W.	—	—	—	—
Termoligas Mineração e Metalúrgia S.A., Sao Paulo.	23°33' S.	46°39' W.	—	—	—	—
CANADA						
Masterloy Products, Ltd., Gloucester, Ontario	45°25' N.	75°42' W.	Converter	Aluminothermic	1,000	—
CHINA						
Emei Ferroalloy plant, Emei, Sichuan	29°35' N.	103°31' E.	Converter	Thermit	—	—
Jinzhou Ferroalloy plant, Jinzhou, Liaoning	41°07' N.	121°06' E.	...do.....	...do.....	3,629	—
Nanjing Ferroalloy plant, Nanjing, Jiangsu	32°03' N.	118°47' E.	...do.....	...do.....	227	—
Shanghai Metallurgical plant #2, Shanghai	31°14' N.	121°28' E.	...do.....	...do.....	—	—
GERMANY						
GfE-Gesellschaft für Elektrometallurgie m.b.H., Nuremberg.	49°27' N.	11°05' E.	Converter	Aluminothermic	2,722	—
HUNGARY						
Otvózetgyar Salgótarjan, Salgótarjan, Nograd County.	48°07' N.	19°49' E.	Converter	—	—	—
INDIA						
Electro Ferro Alloy, Ltd., Ahmedabad, Gujarat.	23°02' N.	72°37' E.	Converter	Thermit	—	—
ITALY						
Salem-SpA Leghe e Metalli, Genoa	44°25' N.	08°57' E.	Converter	Aluminothermic	1,452	—
JAPAN						
Awamura Metal Industry Co. Ltd., Uji City, Kyoto.	34°28' N.	136°43' E.	Converter	Aluminothermic	800	Sub-merged arc furnace.
Japan Metals and Chemicals Co., Ltd., Oguni, NKK Corp., Yamagata Prefecture.	33°11' N.	131°08' E.	...do.....	...do.....	1,814	—
Shimminato City, Toyama	36°48' N.	137°05' E.	—	—	—	—
Taiyo Mining and Industrial Co., Ltd., Ako City, Hyogo Prefecture.	34°44' N.	134°22' E.	Converter	Aluminothermic	1,361	—
LUXEMBOURG						
Continental Alloys S.A. (CASA), Dommeldange.	49°38' N.	06°09' E.	Converter	Aluminothermic	1,089	—
MEXICO						
Ferroaleaciones de México S.A. - Ferromex, Gómez Palacio, Durango.	25°39' N.	103°30' W.	—	—	—	—
ROMANIA						
Tulcea Metallurgical Complex, Tulcea	45°10' N.	25°50' E.	—	—	—	—
SOUTH AFRICA						
Vantra Division, Highveld Steel and Vanadium Co., Ltd., Witbank.	25°55' S.	29°10' E.	Converter	Aluminothermic	—	—

TABLE 9.—Selected production information for ferrovanadium—Continued

Producer	Latitude	Longitude	Plant type	Process	Annual capacity (metric tons)	Comments
SOVIET UNION						
Chusovskoy Metallurgiskiy, Chusovoi, Perm district.	57°21' N.	59°14' E.	Converter	—	—	—
Metallurgicheskiy Zavod Im. Serov, Sverdlovsk district.	59°29' N.	60°31' E.	...do.....	—	—	—
Nizhnetagilskiy Metallurg, Nizhniy Tagil, Sverdlovsk.	57°55' N.	59°57' E.	...do.....	—	—	—
Tulachermet Kombinat, Tula, Tula district	54°12' N.	37°37' E.	Converter	—	—	—
SPAIN						
Ferroastur-Ferroaleaciones Especiales Asturianas, S.A., Poligamo de Maqua, Madrid.	40°25' N.	03°43' W.	Converter	Thermit	1,100	—
SWEDEN						
MPT-Metals and Powders Trollhättan AB, Trollhättan.	58°16' N.	12°18' E.	Converter	Aluminothermic	907	—
UNITED KINGDOM						
London and Scandinavian Metallurgical Co., Ltd., Rotherham, South Yorkshire.	53°25' N.	01°20' W.	Converter	Aluminothermic	544	—
Murex Ltd., Rainham, Essex	51°21' N.	00°36' E.	...do.....	...do.....	1,361	—
UNITED STATES						
Affiliated Metals and Minerals, Inc., New Castle, Pennsylvania.	41°00' N.	80°22' W.	Converter	Aluminothermic	—	—
Reading Alloys Inc., Robesonia, Pennsylvania.	40°22' N.	76°08' W.	...do.....	Thermit	—	—
Shieldalloy Metallurgical Corp., Cambridge, Ohio.	40°02' N.	81°31' W.	...do.....	Aluminothermic	—	—
Strategic Minerals Corp., Niagara Falls, New York.	43°01' N.	79°08' W.	...do.....	...do.....	—	—
Teledyne Wah Chang Albany, Albany, Oregon.	44°34' N.	123°00' W.	Vanadium metal.	—	—	—

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