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# Characterization Factors in the Category of the “Utilization of Mineral Resources”

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## 1. Purpose

When evaluating categories of "mineral resource utilization," environmental aspects such as resource depletion are taken into consideration, and appropriate "inventory" is identified, and given factors that characterize it.

One of the major problems encountered when characterizing the depletion of mineral resources which serves as an important index of LCI (Life Cycle Inventory) analysis is, how to use the database. The present investigation looked at various databases that could be used for this purpose and evaluated them in terms of their reliability, ease of acquisition, size of target ores, and so on. In addition, publicly released data on excavation, production, demand, utilization, distribution, etc., were obtained from government statistics or relevant businesses, among other sources.

## 2. Determining Inventory Items

### 2.1. Inventory Items for "Utilization of Mineral Resources"

#### 2.1.1. "Resources" as economic activities

In the inventory analysis, the use of raw materials is as important as the use of energy, and is an item that has an impact on each subprocess. In the various subprocesses, there are raw materials that have impact as processed materials. Ultimately, their retroactive flow upstream will return them as resources from the earth's environment. In many LCAs, the collection of resources from the earth is employed as the start point of the system. This subsystem, which is called excavation, collection, extraction, etc., exists in the interface of the earth's environment. The transport of excavated, collected materials from the earth environment to the human (economic) sphere is one of the first impacts.

In this paper, the first thing that must be considered as an inventory of Life Cycle Assessment (LCA), is how these impact items are generated as goods flow that occurs during the process by which these materials are brought into the human economic sphere. Here, the term "resources" will be used to refer particularly to mineral resources, from the following 3 perspectives:

Table 2-1 The three different perspectives for "resources"
Geological resources
Minable (economic) resources
Environmental resources

"Geological resources" refers to concepts of classification of deposits, distribution of elements in the earth's crust, and so on, regardless of whether or not said resources can be extracted, and indicates the physical existence as an objective state. While this concept is limited by human probing ability, ability to make educated guesses for unknown areas, and so on, one can argue about "resources" as relatively objective quantities.

In contrast, environmental "resources," which are referred to with generic terms such as "global resources," are relatively subjective resource concepts. For example, when referring to "water resources," the definition of the amount of water of some area can differ depending on who is making the argument and the water resource in question at the time. While there are several important underlying concepts, there are many ambiguities and vagueries in the scientific discussion.

Economic (minable) resources are useful materials which can be economically extracted using existing technologies and techniques. There are two important meanings here. The first regards mineralogical resources. Because the extraction of resources depends on economic and technological feasibility, the volume of such resources will depend on changes in technological and economic conditions. The second meaning is that the term does not include non-economic aspects such as slag and wastewater, especially for environmental resources.

In these three different resource concepts, the item best suited for LCA inventory analysis is "Materials flow generated during the process of bringing resources into the human/economic sphere." Therefore, it is appropriate to refer to them as "minable (economic) resources".

### 2.1.2. Mineral resources that should be examined as inventory items

As mentioned earlier, if we examine the economic aspects of “resources” as inventory items, their definitions will not be clear if they do not correspond exactly with items for economic products.

In this country, the Ministry of Public Management, Home Affairs, Posts and Telecommunications has established the Standard Commodity Classification for Japan and work is being done for standardization. It should be noted here that the Standard Commodity Classification for Japan is contrasted with the Harmonized Commodity Description and Coding System (HS Code) established by the Customs Cooperative Council (CCC). As definitions of goods such as minerals that are frequently on international markets, they should also be viewed as maintaining international uniformity.

When using such product classifications, one should also consider the flow of so-called “bads,” that is, materials (slag) that are not used in economic activities. While there may still be room for debate, an inventory is first put together from a material flow perspective as economic activities. Based on the inventory, excessive input, wastes to be processed or emissions to the environment are to be discussed. Consequently, we examine “resources” here as materials having economic value.

The categories of the Standard Commodity Classification for Japan related to resources are listed below. Category 1 refers to the raw materials and energy resources sectors.

The classifications also include living things and crops. The sectors that are known as mineral resources include

04 Metallic ores

05 Nonmetallic minerals and rock except coal and petroleum

In the energy resource sector, there are

06-1 through 06-3 Coal and coal products

07-1 Crude petroleum and petroleum products

and 08-2 Electric power, gas and water.

This report will make no further mention about energy-related sectors.

Table 1-2 Crude materials and energy resources

Section 1 Crude Materials and Energy Sources		
<p><b>01 Live animals</b></p> <p>01 1 Cattle</p> <p>01 2 Horses</p> <p>01 3 Sheep</p> <p>01 4 Goats</p> <p>01 5 Hogs</p> <p>01 6 Rabbits (except hares and experimental animals)</p> <p>01 7 Poultry and hatching poultry eggs</p> <p>01 8 Seed cocoons and silk-worm eggs</p> <p>01 9 Other live animals</p> <p><b>02 Crude animal products</b></p> <p>02 1 Raw hides and skins (except fur skins)</p> <p>02 2 Fur skins, undressed</p> <p>02 3 Feathers and down raw or crude</p> <p>02 4 Aquatic animal products</p> <p>02 5 Animal materials used in manufacturing drugs</p> <p>02 6 Bones, hoofs and horns</p> <p>02 7 Animal fibres</p> <p>02 9 Other crude animal products, inedible</p> <p><b>03 Crude vegetable products</b></p> <p>03 1 Seeds (except oil seeds)</p> <p>03 2 Oil seeds, oil nuts and oil kernels</p> <p>03 3 Propagating materials (except seeds)</p> <p>03 4 Ornamental plants</p> <p>03 5 Crude wood materials (including bamboo)</p> <p>03 6 tobacco, unmanufactured</p> <p>03 7 Rubber, resins and balsam, unprocessed</p> <p>03 8 Sea weeds, unprocessed, inedible</p> <p>03 9 Other crude vegetable products, inedible</p>	<p><b>04 Metallic ores</b></p> <p><u>04 1 Precious metallic ores</u></p> <p><u>04 2 Nonferrous metallic ores</u></p> <p><u>04 3 Ferrous metallic ores</u></p> <p><u>04 4 Light metallic ores</u></p> <p><u>04 5 Rare metallic ores</u></p> <p><u>04 6 Radioactive minerals</u></p> <p><u>04 9 Other metallic ores</u></p> <p><b><u>05 Nonmetallic minerals and rock except coal and petroleum</u></b></p> <p><u>05 1 Minerals and rocks for construction materials</u></p> <p><u>05 2 Minerals and rocks for industrial materials (except otherwise classified)</u></p> <p><u>05 3 Minerals and rocks for refractory materials</u></p> <p><u>05 4 Minerals and rocks for pottery and porcelain materials</u></p> <p><u>05 5 Minerals and rocks for fertilizer materials</u></p> <p><u>05 6 Minerals usable in respect of properties</u></p> <p><u>05 7 Grinding, abrasives and minerals for industrial art</u></p> <p><u>05 8 Clayey minerals (except otherwise classified)</u></p> <p><u>05 9 Other nonmetallic minerals and rocks (except coal and petroleum)</u></p> <p><b>06 Coal and coal products</b></p> <p><u>06 1 Coal</u></p> <p><u>06 2 Lignite</u></p> <p><u>06 3 Peat and grass coal</u></p> <p>06 4 Coal products (including lignite products)</p> <p>06 9 Other coal and coal products (including lignite products)</p>	<p><b>07 Crude petroleum and petroleum products</b></p> <p>07 1 Crude petroleum and related crude natural products</p> <p>07 2 Petroleum products</p> <p>07 9 Other crude petroleum and petroleum products</p> <p><b>08 Electric power, gas and water</b></p> <p>08 1 Electric power</p> <p><u>08 2 Gas</u></p> <p>08 3 Water (by pipe)</p> <p><b>09 Other crude materials and energy sources</b></p> <p>09 1 Charcoal</p> <p>09 2 Fuel wood</p> <p>09 9 Crude materials and energy sources, n.e.c.</p>

The underlined sections indicate items that pertain to mineral resources.

### 2.1.3. Nonmetallic mineral resources that are included in the inventory

Table 1-2 also includes half-processed and processed goods. Therefore these goods were removed from the analysis; only those items pertaining to mineral resources were used. With that, let us first take a look at Sector 05, Nonmetallic minerals and rock.

On the far left of the table is the standard commodity code. For reference, what is considered to be the corresponding interindustry table code is listed in the second column. However, because the interindustry table code often includes broader concepts, such “higher ranking” concepts are listed in the third column. When the third column corresponds to the second column, then we can conclude that the product code matches the interindustry table code. The fourth column lists the resource names. It is recommended that these names be used as inventory items.

Also for reference, typical constituents, uses, etc., are listed. For example, for materials that are used with a special function in mind, there are occasions in which material flow of the product-making stage subsystem is missing in the flow chart, even for materials that are essential for providing these functions. Therefore, the author would like these applications to be kept in mind to keep them from being left out of the inventory. The first and second columns from the right shows the Japanese domestic demand and rounded off value. When these numbers are large, they can be expected to have a major impact on the frequency of use, upstream processes, etc., so information has been provided to keep them from being left out of the inventory.

Sector 05, Nonmetallic minerals and rock, is further divided into 9 subcategories, which have been listed accordingly. It should be noted that while sometimes there is no product code, applicable items can still be found in a reference called “Basic Knowledge of Mineral Trading” which has no standard commodity code but which is included here for reference.

Table 1-3 05-1 Minerals and rock used as construction materials

Commodity code 05-	Interindustry table code	Interindustry table item	Name of resource	Main component	Application	Domestic demand (kt)	Price (Yen/kg)
11	0622012	stone	<b>granite</b>	SiO <sub>2</sub> .Al <sub>2</sub> O <sub>3</sub> .K <sub>2</sub> O.Na <sub>2</sub> O	stone	1000	30
121	0622012	stone	<b>andesite</b>				
122	0622012	stone	<b>baslt</b>				
13	0622012	stone	<b>tuff</b>				
14	0622012	stone	<b>marble</b>	CaSO <sub>4</sub>	building stone	80	80
151	0622012	stone	<b>slate</b>	SiO <sub>2</sub> .Al <sub>2</sub> O <sub>3</sub> .MgO	roof, interior and exterior parts	10	50
152	0622012	stone	<b>shale</b>				
153	0622012	stone	<b>sand stone</b>				
154	0622012	stone	<b>mud stone</b>				
1611	06220111	sand, gravel	<b>sand</b>				
1612	06220111	sand, gravel	<b>gravel</b>			350000	1.5
1613			<b>cobble stone</b>				
162	06220211	→	<b>gravel stone</b>			400000	1.2
193	0622012	stone	<b>liparite</b>				

Table 1-4 05-2 Minerals and rocks for industrial materials

Commodity code 05-	Interindustry table code	Interindustry table item	Name of resource	Main component	Application	Domestic demand (kt)	Price (Yen/kg)
2111			<b>sulphur</b>	S	rubber, medicine, inorganic chemicals, detergents	1300	330
221			<b>fluorspar</b>	CaF <sub>2</sub>	material for smelting steel and aluminum	567	15
231	0629099303	graphite	<b>graphite</b>	C	carbon products	90	100
24			<b>gypsum</b>	CaSO <sub>2</sub> .2H <sub>2</sub> O	molding materials, cement, medical uses	3000	5
25	06210191	white silica stone	<b>white silica stone</b>	SiO <sub>2</sub>	semiconductor, lens, glass	18000	1
261	06210192	silica sand	<b>silica sand</b>	Sand containing much SiO <sub>2</sub>	sheet glass, glass wool	6500	5
27	0621011	limestone	<b>limestone</b>	CaCO <sub>3</sub>	cement, iron and steel, calcium carbide	200000	1
281	06210193	dolomite	<b>dolomite</b>	CaCO <sub>3</sub> .MgCO <sub>3</sub>	civil engineering and construction, iron and steel, refractory products, lime, glass	4000	1.2
282			<b>zircon sand</b>	ZrO <sub>2</sub> .SiO <sub>2</sub>	ceramics, casting sand, refractory products	80	50
			<b>bauxite</b>	Al <sub>2</sub> O <sub>3</sub> .nH <sub>2</sub> O	Al,Al <sub>2</sub> O <sub>3</sub>		4
			<b>Ilmenite</b>	TiO <sub>2</sub> (FeO)	inorganic chemicals, Ti	700	15
			<b>satın spar</b>	SrSO <sub>4</sub>	fluorescent materials, reagents, cathode-ray tubes	70	30
			<b>alunite</b>	3Al <sub>2</sub> O <sub>3</sub> .4SO <sub>2</sub> .6H <sub>2</sub> O (Na <sub>2</sub> O)	medicine, food, cleansing materials, pigments		
			<b>arsenopyrite</b>	FeAsS	glass depurants, pigments, pesticides	0.4	480

Table 1-5 05-3 Minerals and rocks for refractory materials

Commodity code 05-	Interindustry table code	Interindustry table item	Name of resource	Main component	Application	Domestic demand (kt)	Price (Yen/kg)
32	06210194	pyrophyllite	<b>pyrophyllite</b>	$\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$	ceramic furnace, seal materials, tile	1000	20
33	06210195	fire clay	<b>fire clay</b>	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$	pottery and porcelain, clay brick	700	15
341			<b>magnesite</b>	$\text{MgCO}_3$	refractory products, foods additive, wood preservative, deicing agents	300	8
35			<b>bauxite</b>	$\text{Al}_2\text{O}_3 \cdot n\text{H}_2\text{O}$	$\text{Al}, \text{Al}_2\text{O}_3$		4
361			<b>chromite</b>	$\text{FeO} \cdot \text{Cr}_2\text{O}_3$	iron and steel, chemicals, refractory products	800	15
37	06220112	olivine	<b>olivine</b>	$(\text{Mg}, \text{Fe})_2\text{SiO}_4$	special casting sand	5000	1
3911			<b>silimanite</b>				
3912			<b>kyanite</b>	$\text{Al}_2\text{O}_3 + 2\text{SiO}_2$	pottery and porcelain, clay brick	250	40
3913			<b>andalusite</b>				
			<b>spinel</b>	$\text{MgO} \cdot \text{Al}_2\text{O}_3$	refractory products	20	40

Table 1-6 05-4 Minerals and rocks for pottery and porcelain materials

Commodity code 05-	Interindustry table code	Interindustry table item	Name of resource	Main component	Application	Domestic demand (kt)	Price (Yen/kg)
41	0621019601	feldspar	<b>feldspar</b>	$\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$	ceramics, pottery and porcelain, glass	1000	12
44	06210197	pottery stone	<b>pottery stone</b>	$\text{SiO}_2 \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$	pottery and porcelain	240	7
451			<b>wollastonite</b>	$\text{CaSiO}_2$	rock wool, high-frequency insulator		50
46			<b>petalite</b>	$\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 8\text{SiO}_2$	ceramic materials, cathode-ray tubes, condensers, batteries	5	30
47	06210198	kaolin	<b>kaolin</b>	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$	pottery and porcelain, papermaking and coating, glass fiber	1000	13

Table 1-6 05-5 Minerals and rocks for fertilizer materials

Commodity code 05-	Interindustry table code	Interindustry table item	Name of resource	Main component	Application	Domestic demand (kt)	Price (Yen/kg)
51			<b>phosphate rock</b>	$\text{Ca}_3\text{P}_2\text{O}_5$	fertilizer, inorganic chemicals	1500	10
52			<b>serpentite</b>	$\text{MgO} \cdot \text{SiO}_2$	building materials, fertilizer, iron and steel	6000	
53			<b>caliche</b>	$\text{NaNO}_3$	fertilizer, glass glaze, chemical agents	37	
54			<b>nitrate</b>				
55			<b>potash mineral</b>	$\text{K}_2\text{O}$	fertilizer, gunpowder, photographic agent, dyestuff	1000	

Table 1-7 05-6 Minerals usable in respect of properties

Commodity code 05-	Interindustry table code	Interindustry table item	Name of resource	Main component	Application	Domestic demand (kt)	Price (Yen/kg)
601	0629099301	asbestos	<b>asbestos</b>	$3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$	asbestos products	300	10
602	0629099302	talc	<b>talc</b>	$3\text{MgO} \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$	papermaking filler, synthetic resins, paint, rubber	500	8
603			<b>mica</b>	$\text{K}(\text{Mg}, \text{Fe})_3(\text{Al}, \text{Fe})\text{Si}_3\text{O}_{10}(\text{OH}, \text{F})_2$	electric insulating equipment	2	1000
604	0629099203	diatomite	<b>diatomite</b>		filter, building materials, refractory and heat insulating materials, agriculture	250	20
605	0629099202	ben tonite	<b>ben tonite</b>		casting sand, building bond, pellet materials	500	11
606	0629099204	sericite	<b>sericite</b>		pigments, rubber additive, welding materials, electromagnetic shield	12	150
6071			<b>quartz</b>	$\text{SiO}_2$	optics, IC sealant, crystal oscillator	2	500
608			<b>calcite</b>	$\text{CaCO}_3$	optical materials		500
611			<b>tourmaline</b>				
6121			<b>vermiculite</b>	$\text{MgO} \cdot \text{SiO}_2 \cdot \text{Al}_2\text{O}_3$	lightweight materials, refractory, heat insulating materials, soundproof materials	40	100
6131			<b>perlite</b>	$\text{SiO}_2 \cdot \text{Al}_2\text{O}_3 (\text{Na}_2\text{O}, \text{K}_2\text{O})$	heat and cold insulating materials, detergents, thermal insulation, wall materials	80	100
614			<b>pumice</b>		lightweight aggregate, block	500	
6151			<b>pozzuolan</b>				
	0629099205	zeolite	<b>zeolite</b>	$(\text{Ca}, \text{Na}_2, \text{K}_2)\text{Al}_2\text{Si}_7\text{O}_{18} \cdot 6\text{H}_2\text{O}$	livestock and horticulture industry, water treatment, civil engineering, pesticide carrier	90	25
			<b>pyrophyllite</b>	$\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$	papermaking filler, catalyzers carrier, pesticide, glass fiber	350	30
			<b>attapulgite</b>	$\text{Si}_8\text{O}_{20}\text{Mg}_5(\text{OH})_2(\text{OH}_2)_{4,4}\text{H}_2\text{O}$	absorbent, petroleum refining agents, food additive, cosmetics, detergents	0.8	
			<b>cristobalite</b>	$\text{SiO}_2$	water glass, lightweight aggregate, absorbent		

Table 1-8 05-7 Grinding, abrasives and minerals for industrial art

Commodity code 05-	Interindustry table code	Interindustry table item	Name of resource	Main component	Application	Domestic demand (kt)	Price (Yen/kg)
71			<b>garnet</b>	3(FeO,CaO).Al <sub>2</sub> O <sub>3</sub> .3SiO <sub>2</sub>	jewelry, abrasive	8	20
72			<b>corundum</b>	Al <sub>2</sub> O <sub>3</sub>	abrasive	80	100
73			<b>emery</b>				
74			<b>tripoli</b>				
75			<b>diamond</b>	C	jewelry, abrasive	0.013	1000000
76			<b>agate</b>				
77			<b>amber</b>				
			<b>cleanser</b>	SiO <sub>2</sub> (Al <sub>2</sub> O <sub>3</sub> .Fe <sub>2</sub> O <sub>3</sub> )	abrasive, cleanser	40	40

Table 1-9 05-8 Clayey minerals

Commodity code 05-	Interindustry table code	Interindustry table item	Name of resource	Main component	Application	Domestic demand (kt)	Price (Yen/kg)
81			<b>clay</b>	Al <sub>2</sub> O <sub>3</sub> .SiO <sub>2</sub> .H <sub>2</sub> O	cement, earthen pipes, roof tile	0.3	2
82	0629099201		<b>acid clay</b>		absorbent, petroleum refining agents, foods additive	90	15
83			<b>clorite</b>				

Table 1-10 05-9 Other nonmetallic minerals and rocks

Commodity code 05-	Interindustry table code	Interindustry table item	Name of resource	Main component	Application	Domestic demand (kt)	Price (Yen/kg)
911	06290991	<b>barite</b>	<b>barite</b>	BaSO <sub>4</sub>	paint, papermaking agents, electron device, resins stabilizer	100	8
912			<b>cryolite</b>	3NaF.AlF	materials for smelting aluminum	800	150
93			<b>borax</b>	H <sub>3</sub> BO <sub>3</sub>	glass, pottery and porcelain, electronic components	90	120
94			<b>soda</b>	NaCO <sub>3</sub> .nH <sub>2</sub> O	glass, detergents, chemicals	1000	40
951			<b>rock salt</b>				
952			<b>solar salt</b>				
953				iodine salt water	vinyl chloride, rubber, halogen bulbs	8	

#### 2.1.4 Metallic mineral resources that are included in the inventory

In the Standard Commodity Classification for Japan, Sector 04 is Metallic ores. Resource name is described as, for example, “iron ore“ in this report.

In the classification, minerals that contain copper, lead and/or zinc are listed as “Cu/Pb/Zn ores.” However, 1) the composition varies greatly depending on the mine so it is difficult to generalize, and 2) when a resource is taken retroactively from a product, a complex pattern of “Cu/Pb/Zn” is not obtained; only what is necessary is taken out. For these reasons, it is better to use the ore names when referring to a combination of major metals. (However, it should be noted that some parts have allocation problems, and there are still areas that are open for interpretation).

In addition, the classification of standard commodities includes other minerals in production in Japan, so the metals that are extracted during the refining process for other metals are not given ore names. For the same reason as noted earlier, ore names are given in based on the metallic elements that exist in the rock. These parts are denoted by the \* in the table.

Typical minerals are given geological or chemical names. Ores having metal-bearing minerals are called gangue ores, which have a mixture of minerals. Ores as they are extracted from the earth are called “crude ores.” Most of these go through a “dressing” process which separates them into “concentrates” and “tailings”. “Dressing” should be treated as a subprocess that involves the introduction of materials, energy, solvents, etc. “Concentrates” are intermediate products; for purposes of this paper, “crude ores” are the focus of “resource” discussion.

In addition, as with the table for nonmetallic minerals, this table lists the main uses, the domestic demand and price. Furthermore, the lines are in the order of, from greatest to least, the domestic demand × price. The higher the position, the greater the socio-economic position it occupies; thus, it can be considered to be a reflection of the importance of the omission check as inventory.

The table also lists the year of discovery. The newer the discovery, the greater the possibility that it is being used for new applications, so their omission from the inventory should be avoided at all costs.

Table 1-11 Metal mineral resources

Metal	Name of resource	Representative mineral	Main application	Domestic demand (t/y)	Price (Yen/g)	Discovery year
Fe	<b>iron ore</b>	hematite, Fe <sub>2</sub> O <sub>3</sub> magnetite, Fe <sub>3</sub> O <sub>4</sub>	structural material	80,000,000	0.03	ancient times
Au	<b>gold ore</b>	native gold, accompanied with chalcocopyrite	electronic components, plating materials,	370	1000	ancient times
Al	<b>bauxite</b>	bauxite, Al(OH) <sub>3</sub> .nH <sub>2</sub> O	light metal	1,800,000	0.2	1825
Cu	<b>copper ore</b>	chalcocopyrite, CuFeS <sub>2</sub>	electric components, alloys	1,500,000	0.22	ancient times
Ni	<b>nickel ore</b>	millerite, NiS garnierite	batteries, alloys, lead frames	211,000	1.3	1751
Pd	<b>platinum group</b>	native platinum	catalyzers, hydrogen permeable materials	70	2500	1803
Mo	<b>molybdenum ore</b>	molybdenite, MoS <sub>2</sub> wulfenite, PbMoO <sub>4</sub>	antifriction, catalyzers, alloys	26,000	6	1782
Pt	<b>platinum group</b>	native platinum	catalyzers, experimental materials	60	2000	1748
Li	<b>lithium ore</b>	lepidolite, KL <sub>2</sub> Si <sub>4</sub> AlO <sub>10</sub> (OH) <sub>2</sub>	batteries	10,000	10	1817
Zn	<b>zinc ore</b>	zinc blende, ZnS (accompanied with zinc)	plating materials, alloys	650,000	0.13	medieval times
Ag	<b>silver ore</b>	argentite, Ag <sub>2</sub> S, native silver, accompanied with zinc blende or galena	sensitized materials, chemicals	3,500	18	ancient times

Nb	<b>niobium ore</b>	columbite, (Fe,Mn)(Ta,Nb) <sub>2</sub> O <sub>6</sub>	alloys, condensers	4,800	9	1801
Si	<b>silicon ore*</b>	silica rock, silica sand, quartz	semiconductors, chemical materials, iron and steel	200,000	0.2	1824
W	<b>tungsten ore</b>	scheelite, CaWO <sub>4</sub> , wolframite, (FeMn)WO <sub>4</sub>	filaments, machine tools	6,500	5	1783
Ti	<b>titanium ore</b>	ilmenite, FeTiO <sub>3</sub> , rutile, TiO <sub>2</sub>	medical alloys, aircraft, oxidized substances, catalyzers	20,000	1.4	1791
Ta	<b>tantalum ore</b>	columbite, (Fe,Mn)(Ta,Nb) <sub>2</sub> O <sub>6</sub>	alloys, condensers, solar cells	320	80	1801
Pb	<b>lead ore</b>	galena PbS, (accompanied with zinc)	storage batteries, solder	250,000	0.08	ancient times
Rh	<b>platinum group</b>	native platinum	thermocouples	2	8700	1803
Ce	<b>rare earth ore</b>	monazite	magnetic materials, colorants	5,000	3	1839
Ga	<b>gallium ore*</b>	accompanied with zinc	semiconductors, fiber optics	116	70	1875
Mn	<b>manganese ore</b>	pyrolusite MnO <sub>2</sub> , rhodochrosite, MnCO <sub>3</sub>	dry cells, alloys	66,000	0.1	1774
Nd	<b>rare earth ore</b>	monazite	magnetic bodies	1,645	4	1885
Mg	<b>magnesium ore</b>	dolomite, CaCO <sub>3</sub> .MgCO <sub>3</sub> , magnesite, MgCO <sub>3</sub>	light metal alloys	30,000	0.2	1808
Be	<b>beryllium ore</b>	beryl, Be <sub>3</sub> Al <sub>2</sub> Si <sub>6</sub> O <sub>18</sub>	special glass, alloys for integrated circuits, connectors	50	100	1797
Co	<b>cobalt ore</b>	<b>cobaltite</b> , (CoFe)AsS	catalyzers, alloys, batteries, magnetic materials	1,100	4	1735
Zr	<b>zirconium ore</b>	zircon, ZrSiO <sub>4</sub>	refractory, lead frames	600	7	1789
As	<b>arsenic ore</b>	arsenopyrite, FeAsS, realgar, AsS, orpiment, As <sub>2</sub> S <sub>3</sub>	semiconductors, insecticides	52	80	medieval times
Ca	<b>Limestone</b>	limestone, CaCO <sub>3</sub>	material for chemical products	285	13	1808
In	<b>indium ore*</b>	accompanied with zinc blende or galena	liquid crystal electrodes, solar cells	85	40	1863
Y	<b>rare earth ore</b>	monazite, (Ce,La,Y,Th)PO <sub>4</sub>	fluorescent materials, sensors, batteries	370	8.5	1794
Cr	<b>chrome ore</b>	chromite, FeCr <sub>2</sub> O <sub>4</sub>	alloys, plating materials, connectors	2,000	1.5	1798
Ge	<b>germanium ore*</b>	accompanied with zinc ore	fiber optics, solar cells, polyethylene terephthalate products	30	100	1886
V	<b>vanadium ore</b>		secondary cells	5,000	0.5	1830
U	<b>uranium ore</b>	uraninite, UO <sub>2</sub> , autunite, Ca(UO <sub>2</sub> ) <sub>2</sub> (PO <sub>4</sub> ) <sub>2</sub> nH <sub>2</sub> O	nuclear fuels	1,000	2	1789
Sr	<b>strontium ore*</b>	celestite, SrSO <sub>4</sub> , strontianite, SrCO <sub>3</sub>	pigments	67	20	1808
La	<b>rare earth ore</b>	monazite	condensers, heating elements	650	2	1839
Bi	<b>bismuth ore</b>	bismuthinite, Bi <sub>2</sub> S <sub>2</sub> , accompanied with zinc blende or galena	fusible alloys, optical products	550	2	medieval times

Sm	<b>rare earth ore</b>		magnetic materials	200	5	1880
Eu	<b>rare earth ore</b>		fluorescent materials	15	60	1901
Cd	<b>cadmium ore*</b>	accompanied with zinc blende	batteries	2,200	0.25	1817
Te	<b>tellurium ore*</b>	accompanied with gold, silver, and copper	optical disks	50	10	1783
Cs	<b>cesium ore*</b>	accompanied with lepidolite	vacuum tubes	42	10	1860
Sn	<b>tin ore</b>	cassiterite, SnO <sub>2</sub> , stannite, Cu <sub>2</sub> FeSnS <sub>2</sub> , stream tin	solder, plating materials	650	0.6	ancient times
Se	<b>selenium ore*</b>	accompanied with copper	rectifiers, copying machines, glass	600	0.5	1818
Sb	<b>antimony ore</b>	stibnite, SbS	type metal	800	0.16	medieval times
Re	<b>rheniite*</b>			1	100	1925
Hf	<b>hafnium ore*</b>	accompanied with zirconium	highly efficient transistors, reactor control rods	2	20	1923
Hg	<b>mercury ore</b>	cinnabar, HgS	laboratory machines, electric equipment, lighting equipment	25	1	ancient times
Os	<b>platinum group</b>	native platinum	fountain pens	2900		1804
Ir	<b>platinum group</b>	native platinum		1750		1804
Ru	<b>platinum group</b>		solar cells	550		1844
Tb	<b>rare earth ore</b>		fluorescent materials, magneto-optical memory	80		1843
Er	<b>rare earth ore</b>			20		1843
Gd	<b>rare earth ore</b>	gadolinite	optical glass, x-ray sensitizers	18		1880
Dy	<b>rare earth ore</b>		magneto-optical memory, magnets	12		1886
Yb	<b>rare earth ore</b>	xenotime		10		1879
Sc	<b>rare earth ore</b>		metal halide lamps	4		1879
Pr	<b>rare earth ore</b>		coloring agents	3		1885
Th	<b>thorium ore</b>	monazite	refractory alloys			1829
Rb	<b>rubidium ore*</b>	accompanied with lepidolite	cathode-ray tubes			1861
Tl						1861
Ho	<b>rare earth ore</b>	xenotime, gadolinite				1879
Tm	<b>rare earth ore</b>	xenotime, gadolinite				1879
Po						1898
Ra	<b>radium ore*</b>		medical uses			1898
Ac						1899
Lu						1907
Pa						1917

### 2.1.5. Inventory units

In order to conduct inventory analysis, it is necessary to enumerate items and clarify the units for the amounts to be evaluated.

The unit for most normal products is that which represents the functionality of the product. In the case of structural materials, the weight (mass) of all materials is most commonly used. However, in the case of mineral resources, it is not the total volume but the volume of the economically valuable materials the resource contains. Thus the unit has to set accordingly. This is especially true for metallic minerals, as can be seen in Table 1-11, “Typical Minerals.” Metallic ores in the same category are considered to be the same type of ore, though they may vary greatly in composition and structure. Furthermore, even if the composition is the same, the ratio to gangue minerals may vary widely from mine to mine.

Accordingly, for metallic ores, the amount evaluated is not the volume of “crude ore,” but the “weight of the target mineral contained in the crude ore.” This corresponds with the amount evaluated for economic activities.

On the other hand, in the case of nonmetallic minerals, it is more important to have uniform features for all elements, such as crystalline structure and associated level of dispersion rather than the composition. In such a case, the condition inside the extracted resource is not the problem — the problem is the total weight of the resource itself. Therefore, with nonmetallic minerals and ores, it is proper to use the weight of the ore as the evaluation weight.

Thus the weight of “mineral itself” or “metal constituent” is used as the evaluation weight, depending on the type of mineral. However, in many cases the unit weight is not standardized because of trading customs. In most cases the metric unit should be used. The next table shows how to convert units of different systems.

Table 1-12 Conversion table for evaluation weights

Unit	Metric weight	Explanation
Pound (lb)	453.6g	English system
Ounce (oz)	28.35g	1/16 lb. Rarely used with precious metals (troy ounce is standard)
(TOZ) Troy ounce	31.1035g	Often used with gold and platinum (and silver)
Short ton	907.18kg	2000lb. (US ton) Used to express weight of resources mainly in the USA, Canada, and South Africa
Long ton	1016kg	2240lb. (UK ton) Used in the UK. Called an “English ton”
Metric ton	1000kg	Metric system (French tonne)
Carat	200mg	Unit of weight for gemstones such as diamonds
Flask	34.5kg	Mercury

## 2.2. Stress Factor Categories of “Utilization of Mineral Resources”

### 2.2.1. Two stress categories for “Utilization of Mineral Resources”

There are two aspects to indicate the effect that the mineral resource use category has on sustainability:

- a) the consumption of minerals as depletable resources, and
- b) the stress on the environment caused by the extraction of mineral resources.

Resource depletion is one of the main themes of this report. As the term implies, it refers to depletion of a resource through consumption, inputs of energy, etc., needed to obtain said resource increase to point of making extraction unfeasible. This has a direct effect of losing the production base that future generations will need for using the resource.

One of today’s effects is the environmental stress that occurs with extraction. That is, resources do not exist by themselves but are mixed in with various other resources. In other words, to extract a

certain resource, extra effort has to be made to get other, non-target resources (in the wide sense of the meaning). This is especially true for mineral resources which have to be extracted from substances that contain them in very minute amounts; the amount of the minerals themselves is far exceeded by the amount of extraneous material. While it is possible at the inventory analysis stage to consider this part as an inventory item for the resource extraction process, there are numerous cases where the transport, substitution, etc., of related resources are not economically feasible, making it difficult to adopt this to other inventory items.

While these two aspects are closely interrelated, they are essentially different types of problems. When looking at the environmental impact of mineral resource use, one must keep these two aspects in mind.

### 2.2.2. Loss of sustainable acquisition of resources in conjunction with “Utilization of Mineral Resources”

The term used to refer to the loss of sustainable acquisition of resources in conjunction with “mineral resource use” is “resource depletion”

“Resource depletion” does not refer to the complete disappearance of a resource. In terms of sustainability, it means

- a) the conspicuous loss of future generations’ ability to acquire the resource,
- b) the necessity for large amounts of inputs and the increasing difficulty in extracting a resource, and
- c) Economic activities dependent on this resource become difficult.

Specifically, as it regards the target resource,

- i) the price of the resource rapidly increases,
- ii) environmental destruction related to the acquisition of the resource becomes quite noticeable, and
- iii) there are diminishing returns for economic activities based on the resource.

Although it is not on a global scale, we are experiencing resource depletion on a regional scale. The following table, for example, shows the amount of proven reserves in Japanese mines in 1998. The grade of proven ores is extremely close to the most marginal extractable grade, clearly indicating that the economic merits are disappearing.

Metallic mineral name	Number of investigated ores	Amount of reserves	Grade of reserves	Amount of extractable crude ore	Grade of extractable crude ore	Amount of real reserves
gold ore	7	2,350 kt	33.5 g/t	1,700 kt	43.5 g/t	74 t
silver ore	7	3,490 kt	112.5 g/t	2,790 kt	84.3 g/t	2,353 t
copper ore	3	1,480 kt	0.4%	1,680 kt	0.3%	5,113 t
lead and zinc ore	4	24,420 kt	lead: 0.8% zinc: 6.1%	19,190 kt	lead: 0.6% zinc: 4.8%	lead: 119 kt zinc: 910 kt
iron ore	5	315 kt	47.4%	226 kt	42.3%	96 kt
iron sand	4	46 kt	1.4%	26 kt	2.3%	585 t
metallic manganese	9	659 kt	16.6%	442 kt	15.3%	68 kt
chromite	4	145 kt	32.9%	170 kt	19.9%	34 kt
tungsten ore	4	233 kt	1.61%	227 kt	1.32%	3 kt

The next table shows the years when important mines in Japan were opened and closed. Japan was once called “the Land of Gold,” and even during the isolationist Edo Period the country was a major world exporter of silver. Today, however, all of the mines, with the exception of Toyoha and a few gold mines, are in danger of being closed, and some mines, like the one at Kamioka, are open as experimental facilities. We are at the stage right before sustainability of mineral mining is lost. Before reaching that stage, we must use the term “depletion” when evaluating this sustainability.

Mine	Region	Type of mineral ore	Year opened	Year closed
Konomai Mine	Hokkaido Pref.	Au	1915	1973
Toyoha Mine	Hokkaido Pref.	Au, Ag, Cu, Pb, Zn	1907	open
Yubari Coal Mine	Hokkaido Pref.	Coal		1990
Oppu Mine	Aomori Pref.	Pb, Zn		1978
Hanaoka Mine	Akita Pref.	Au, Ag, Cu, Zn, Pb		1994
Kosaka Mine	Akita Pref.	Ag, Cu, Zn, Pb, Fe		1990
Osarizawa Mine	Akita Pref.	Cu	708	1978
Ani Mine	Akita Pref.	Cu	1302	1970
Kamaishi Mine	Iwate Pref.	Fe		1993
Iwakura Mine	Miyagi Pref.	Coal		2000
Ooya Mine	Miyagi Pref.	Au	1905	1971
Shishiori Mine	Miyagi Pref.	Au, Ag	1898	1942
Hosokura Mine	Miyagi Pref.	Pb, Zn	900	1997
Tochihara Mine	Ibaraki Pref.	Au		inactive
Handa Mine	Fukushima Pref.	Ag	1598	1950
Takadama Mine	Fukushima Pref.	Au	1573	1976
Ashio Mine	Tochigi Pref.	Cu	1610	1973
Oohito Mine	Shizuoka Pref.	Au, Ag	1600	1973
Izu Yugashima Kanayama Mine	Shizuoka Pref.	Au, Ag	partially open	
Nawaji Mine	Shizuoka Pref.	Au, Ag		1960's
Seigoshi Mine	Shizuoka Pref.	Au, Ag		1987
Toi Mine	Shizuoka Pref.	Au, Ag	1370	1965
Izu Amagi Mine	Shizuoka Pref.	Au, Ag		uncertain
Sado Mine	Niigata Pref.	Au, Ag	1601	1988
Akatani Mine quarry is mined	Niigata Pref.	Fe, Zn	1800's	only limestone
Kamioka Mine	Gifu Pref.	Ag, Zn, Pb, Fe	720	2001
Ogoya Mine	Ishikawa Pref.	Cu, Pb, Zn	1682	1962
Nakatatsu Mine	Fukui Pref.	Zn	1250	1987
Kishu Mine	Mie Pref.	Cu		1987
Komori Mine	Kyoto Pref.	Cu	ca. 1916	1973
Kaneuchi Mine	Kyoto Pref.	Sn	ca. 1910	1982
Shinootani Mine	Kyoto Pref.	Mn		1983
Ootani Mine	Kyoto Pref.	W		1983
Tada Mine	Hyogo Pref.	Ag, Cu, Pb, Zn	15-16th century	1973
Akenobe Mine	Hyogo Pref.	Ag, Sn, Cu	6-8th century	1987
Ikuno Mine	Hyogo Pref.	Ag, Cu	8-12th century	1985
Omidani Mine	Hyogo Pref.	Au, Ag		1985
Sakoshi Otomari Mine	Hyogo Pref.	Au	1974	1984
Asahi Mine	Hyogo Pref.	Au	1911	1920
Yanahara Mine	Okayama Pref.	Fe		uncertain
Besshi Mine	Ehime Pref.	Cu	1690	1973
Iwami Mine	Shimane Pref.	Ag	1309	1945
Kaijima Coal Mine	Fukuoka Pref.	Coal	1885	1976
Miike Coal Mine	Fukuoka/ Kumamoto Pref.	Coal	1889	1997
Taio Mine	Oita/Fukuoka Pref.	Au	ca. 1890	1970
Obira Mine	Oita Pref.	Fe		after the war
Kushikino Mine	Kagoshima Pref.	Au, Ag	17-19th century	open
Hishikari Mine	Kagoshima Pref.	Au, Ag	1975	open

### 2.2.3. Loss of sustainability of surrounding environment in conjunction with “Utilization of Mineral Resources”

The “mineral resource use” category includes two aspects of resource depletion: actual consumption of the mineral resource, and the environmental stress caused by the extraction of the resource. The latter can be divided into the following:

- (1) Changes that are induced not only the amount of minerals that can be obtained from the global environment, but also from other human activities that occur in conjunction with mineral extraction, and
- (2) Total Material Requirement (TMR).

The TMR is a factor that should be considered as an evaluation function. This “eco-backpack” was proposed by Schmidt-Bleek et al. as an effective way to express environmental stress factors related to materials use. The US Environmental Protection Agency (EPA) gives TMR the same importance as “increasing the useful life of product systems” as MIPS (material input per service) TMR is also given consideration in Resource Productivity, Eco-efficiency, and the World Resource Institute coordinates are using it as an index at the policy level for multi-year surveys in the EU and for making calculations and comparisons of international and domestic sections in Japan, the US, Germany and the Netherlands. However, there are many issues that are still not clear, such as calculation bases, and is apparently lacking the objectivity that data need for incorporation into sensitive additive methods such as LCA.

In regards to the important parts covered by TMR, i.e., metals and important components involved with ore excavation (earth and rock), they are calculated by the TMR ore section (hereafter, ore-TMR), which is based on surveys by numerous and expansive mines. Based on that data, ore grade is roughly estimated using data on level of presence in the earth’s crust obtained relatively easily from the literature.

TMR is defined precisely in the Resource Flows published by the World Resource Institute as follows:

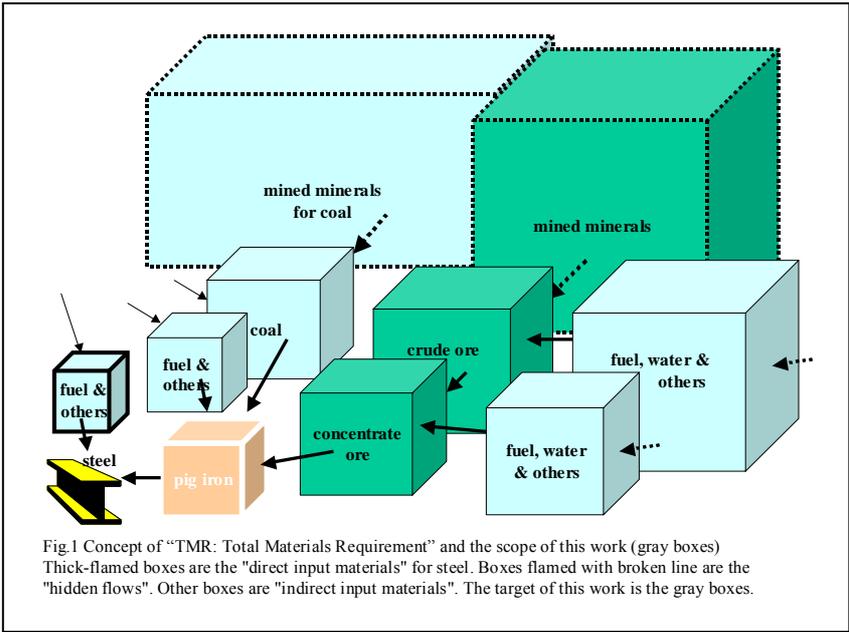
$$\begin{aligned} \text{TMR} = & \Sigma (\text{amounts of direct inputs}) \\ & + \Sigma (\text{amounts of indirect inputs}) \\ & + \Sigma (\text{hidden materials flow}) \quad (1) \end{aligned}$$

where, the amounts of direct inputs and indirect inputs are the respective amounts of direct and indirect inputs as economic activities. They are derived as commodity materials flow which is an amount that is obtainable from a variety of economic statistics. The hidden materials flow (HMF) is an essential concept of TMR.

HMF refers to the transfer and disturbance of materials that occurs in activities besides direct and indirect economic activities. It includes such facets as the movement of earth and rock during excavation, the cutting of forested areas, alteration of water systems, and even the total amount of materials required for the preservation of the landscape, the rehabilitation of the land, and so on. In the international joint report Resource Flow<sup>7)</sup> HMF is examined from two perspectives: ancillary flow, and disturbed flow. Ancillary flow refers to the volume of materials, such as rock and earth, that are moved from a natural state in order to excavate ores and is an integral part of this economy activity. Disturbed flow refers to the volume of natural resources such as water and soil that exist in a non-natural state due to changes that are made during the development of infrastructure, such as factories, land reclamation, and even transport. For phenomena that occur near the boundaries of disturbed flow environments, there are many ways, such as with LCA, etc, that the range of system boundaries can be interpreted, so there has been much debate about disturbed flow. As a result, the present debate about TMR nearly always extends only to ancillary flow

Figure 1 shows an example of the TMR concepts for steel. The materials directly input into steel materials include pig iron and fuels that are characterized as rectangular columns with bold edge lines, and other related materials. To obtain these materials (especially pig iron), it is necessary to make

indirect inputs, such as iron ore and coke, and each of these requires indirect inputs such as fuel, additives, and adjusters required for processing. Coarse ores excavated straight from the ground are needed as raw materials for the dressing process to raise the grade as concentrate. Furthermore, because coarse ores exist in the ground, shafts must be drilled down to where the ore is, or the covering material (rock and earth) must be removed to extract the ore in open pit mining. The slag, overburden, etc., that is



created during this process, as well as the gangue material that holds the ore together, the spring water in the shaft that is exposed due to the excavation, etc., are not the objects of economic transactions, so they are not clearly distinguished in the economic and other statistics. Nevertheless, the entire volume of these materials has a direct impact on the environment. As previously mentioned, this part is the "hidden material flow." It is found not only the flow of iron ore but also in coal; it is certainly considered to be on the boundary with the global environmental side of all indirect inputs. However, the figure only shows the parts which are related to coal and iron ore, which are shown with the rectangular column outlined with the broken lines. The summation of all the rectangular columns in the figure corresponds to TMR. The rectangular column demarcated by the dotted line represents hidden material flow which is called the "eco-backpack" because of a meaning in the back ground. In Japan, it is quantified, for example, as the "shadowy spirit of materials."

The following table shows calculated TMR values.

Table 1. ore-TMR and its global amount of each metals

	Ore-TMR		fundamental data				ore-TMR		fundamental data		
	ore-TMR <sup>b)</sup> [t/metal-t]	annual ore-TMR in the world [Mt/y]	world annual production <sup>b)</sup> [t/y]	crude ore quality <sup>c)</sup> [%]	concentration in the crust <sup>d)</sup> [ppm]		ore-TMR <sup>b)</sup> [t/metal-t]	annual ore-TMR in the world [Mt/y]	world annual production <sup>b)</sup> [t/y]	crude ore quality <sup>c)</sup> [%]	concentration in the crust <sup>d)</sup> [ppm]
Au	1,800,000.0	4,401.0	2,445.00	0.00011 <sup>h)</sup>	0.003	Li	1,400.0	18.2	13,000.00	0.14	1
Cu	<b>300.0</b>	3,870.0	12,900,000.00	0.84 <sup>h)</sup>	75	Tb	<i>30,000.0</i>	17.2	574.00 <sup>g)</sup>		0
Fe	<b>5.1</b>	2,912.1	571,000,000.00	25 <sup>h)</sup>	70700	Gd	<i>10,000.0</i>	16.4	1,640.00 <sup>g)</sup>		3
Ag	160,000.0	2,864.0	160,000.00	0.0013 <sup>h)</sup>	0.08	Ru	800,000.0	16.0	19.99 <sup>g)</sup>	0.00025 <sup>h)</sup>	0.00
U	<i>11,000.0</i>	1007.8	45,807.00 <sup>g)</sup>		0.91	Si	4.5	15.3	3,400,000.00	44	26770
Bi	<i>150,000.0</i>	491.4	17,900.00		0.06	Sn	43.0	8.6	200,000.00	4.65 <sup>h)</sup>	2
Zn	<b>43.0</b>	344.0	8,000,000.00	5.5 <sup>h)</sup>	80	Zr	540.0	7.7	14,250.00	0.37	10
Pd	1,800,000.0	318.6	177.00	0.00011 <sup>h)</sup>	0.001	Ir	2,400,000.0	7.6	3.18 <sup>g)</sup>	0.000084 <sup>h)</sup>	0.000
Pb	<b>95.0</b>	283.1	2,980,000.00	1.33 <sup>h)</sup>	8.0	Y	<i>2,700.0</i>	6.5	2,400.00		2
Pt	1,400,000.0	249.2	178.00	0.00014 <sup>h)</sup>	0.005	Ta	12,000.0	6.2	513.00	0.017 <sup>h)</sup>	1
Ni	200.0	246.0	1,230,000.00	1.02 <sup>h)</sup>	105	Dy	<i>9,000.0</i>	5.9	656.00 <sup>g)</sup>		3
Al	<i>10.0</i>	239.0	23,900,000.00		84100	Mg	20.0	5.7	284,000.00	10	3200
Mo	2,000.0	224.0	112,000.00	0.1 <sup>h)</sup>	1.0	W	170.0	5.4	31,500.00	1.2 <sup>h)</sup>	
Sr	<i>500.0</i>	149.3	304,000.00		260	Lu	<i>45,000.0</i>	5.2	114.80 <sup>g)</sup>		0
Cr	<b>8.9</b>	121.4	13,700,000.00	23 <sup>h)</sup>	185	Br	<i>9,400.0</i>	4.9	520.00		0.3
Ce	<i>2,000.0</i>	70.3	35,014.00 <sup>g)</sup>		33	Hg	2,000.0	3.6	1,800.00	0.1	0.0
V	1,500.0	63.0	42,000.00	0.14	230	Er	<i>12,000.0</i>	3.0	246.00 <sup>g)</sup>		2
Rh	2,600,000.0	62.3	23.96 <sup>g)</sup>	0.000078 <sup>h)</sup>	0.001	Tm	<i>40,000.0</i>	2.7	65.60 <sup>g)</sup>		0.3
Mn	8.0	59.6	7,450,000.00	25 <sup>h)</sup>	1400	Hb	<i>25,000.0</i>	2.5	98.40 <sup>g)</sup>		0.7
La	<i>2,000.0</i>	58.5	18,860.00 <sup>g)</sup>		16	Eu	<i>20,000.0</i>	1.6	82.00 <sup>g)</sup>		1
In	200,000.0	44.0	220.00	0.001	0.05	Se	1,000.0	1.4	1,400.00	0.2 <sup>h)</sup>	0.0
Nd	<i>3,000.0</i>	25.1	13,940.00 <sup>g)</sup>		16	Hf	<i>10,000.0</i>	1.2	123.50		3
Cd	2,000.0	38.6	19,300.00	0.1	0.1	As	29.0	1.2	40,000.00	6.9	1
Te	<i>270,000.0</i>	33.8	125.00		0.02	Re	20,000.0	0.9	43.00	0.01	0.000
Nb	1,400.0	33.0	23,600.00	0.14	11	Be	2,400.0	0.9	356.00	0.08	1
Co	870.0	28.1	32,300.00	0.23 <sup>h)</sup>	29	Ga	<i>3,000.0</i>	0.7	210.00		18
Pr	<i>8,000.0</i>	15.1	3,362.00 <sup>g)</sup>		3.9	Ge	8,300.0	0.5	58.00	0.024	1
Sb	200.0	24.2	121,000.00	0.99 <sup>h)</sup>	0.2	Th	<i>9,000.0</i>	0.4	45.00		3
Yb	<i>12,000.0</i>	23.6	1,958.00 <sup>g)</sup>		2.2	Ti	6.3	0.3	51,000.00	31	540
Sm	<i>9,000.0</i>	22.1	2,460.00 <sup>g)</sup>		3.5	Os	2,000,000.0	0.1	0.06 <sup>g)</sup>	0.0001 <sup>h)</sup>	0.00
B	<i>4,300.0</i>	18.4	4,270.00		10						

While these values are direct amounts, but as far as depletion goes, it cannot be handled in a simple manner. The amount of resources is dependent on the technology of the age and other factors and is therefore not fixed.

## 2.3. Discussion Related to the Sustainability (Depletion) of Mineral Resources

### 2.3.1. Basic terminology

The definitions used for the amount of minerals, proven reserves, etc., are sketchy, and they may differ depending on the database. There are many other confusing aspects as well; for example, concepts in related fields may use identical terminology, or the terminology may be different for the same concept.

#### (1) Identical terms used for similar concepts

Resource: May be referred to as geological resource, mineral resource, environmental resource

Deposit: May be referred to as geological deposit, mineral deposit.

As with the concept of “resource” which we have already touched upon, the concept of “deposit” can refer to “geological deposit” as an actual entity having concentrated components, or as a mineral deposit which can be expected to have economic value and thus be excavated from a geological

deposit. As we saw earlier, there are geological deposits that exist in Japan, but its mineral deposits are prone to depletion.

(2) Different terms used to describe identical concepts in different fields

Life of resource and years of minability:

Basically, both of these expressions refer to the reserves divided by the amount that are extracted in a year. However, the “life of resource” is used for mineral resources, whereas “years of minability” refers to energy resources such as coal, oil, and natural gas. Therefore, the “life of resource” is an economic concept that indicates the period of time that a target material can fulfill its function and is used in this case because of the concept of the mineral resource as an asset that creates value. Energy resources are rather flow element that are expressed in regard to the sustainability of their extraction process.

Reserve and minable reserve

“Minaable reserve” is a term used by JIS which in nearly the same context as “reserve.”

(3) Mixture of several concepts

There is a particularly large number of expressions, especially from the economic aspects, used to described the reserve, but the most authoritative of these is the terminology used by the US Bureau of Mines, which is adequate for most cases.

Therefore, the amount of reserve (ore reserve) is first defined as the “reserve base,” which then provides the basis for the following definitions:

Reserves (ore reserves) refers to the amount of minerals among the reserve base that can be extracted or produced at the time the decision is made for economic production.

The “reserve base,” which forms the basis for the above definition, is defined as “the part of identified resources which satisfies the strictly limited minimum physical and chemical standards related to current excavations and operations. These standards include grade, ore quality, thickness and depth, among other factors.”

Thus, “reserve base” is understood to refer to the part which is technically feasible to extract, while “reserve (ore reserves)” refers to the amount within the reserve base that can be economically extracted.

There are other concepts such as marginal reserves, effective deposits, subeconomic deposits, etc. Their interrelationship can be expressed with the following equation:

Effective deposits = Reserves + Marginal reserves

Marginal reserves: refers to mineral resources on economic threshold

Identified mineral deposits = Identified ore reserves = Mineral resources

= Reserves + Marginal reserves + Subeconomic mineral resources

Subeconomic mineral deposits = Subeconomic mineral resources

: deposits that are below the level of economic feasibility

Total mineral resources = Resources + Undiscovered resources

Undiscovered deposits, or potential mineral resources: deposits which have not yet been discovered.

Professor Tatsumi of Hiroshima University translated the definitions of the US Bureau of Mines into Japanese. These Japanese definitions can be viewed at the following web site: [http://home.hiroshima-u.ac.jp/er/Rres\\_R\\_K1.html](http://home.hiroshima-u.ac.jp/er/Rres_R_K1.html)

# Principles of a Resource/Reserve Classification for Minerals

By the U.S. Bureau of Mines and the U.S. Geological Survey

## U.S. Geological Survey Circular 831, 1980

A revision of the *classification* system published as U.S. Geological Survey Bulletin 1450-A

### Introduction

Through the years, geologists, mining engineers, and others operating in the **minerals** field have used various terms to describe and classify mineral resources, which as defined herein include energy materials. Some of these terms have gained wide use and acceptance, although they are not always used with precisely the same meaning.

Staff members of the **U.S. Bureau of Mines** and the **U.S. Geological Survey** collect information about the quantity and quality of all mineral resources, but from different perspectives and with different purposes. In 1976, a team of staff members from both agencies developed a common **classification** and nomenclature, which was published as **U.S. Geological Survey** Bulletin 1450-A - "**Principles** of the Mineral Resource **Classification** System of the **U.S. Bureau of Mines** and **U.S. Geological Survey**." Experience with this resource **classification** system showed that some changes were necessary in order to make it more workable in practice and more useful in long-term planning. Therefore, representatives of the **U.S. Geological Survey** and the **U.S. Bureau of Mines** collaborated to revise Bulletin 1450-A

Long-term public and commercial planning must be based on the probability of discovering new deposits, on developing economic extraction processes for currently unworkable deposits, and on knowing which resources are immediately available. Thus, resources must be continuously reassessed in the light of new geologic knowledge, of progress in science and technology, and of shifts in economic and political conditions. To best serve these planning needs, known resources should be classified from two standpoints: (1) purely geologic or physical/chemical characteristics - such as grade, quality, tonnage, thickness, and depth-of the material in place: and (2) profitability analyses based on costs of extracting and marketing the material in a given economy at a given time. The former constitutes important objective scientific information of the resource and a relatively unchanging foundation upon which the latter more variable economic delineation can be based.

The revised **classification** system, designed generally for all mineral materials, is shown graphically in figures 1 and 2 (see page 5); its components and their usage are described in the text. The **classification** of mineral and energy resources is necessarily arbitrary, because definitional criteria do not always coincide with natural boundaries. The system can be used to report the status of mineral and energy-fuel resources for the Nation or for specific areas.

### Resource/Reserve Definitions

A dictionary definition of resource, "something in reserve or ready if needed," has been adapted for mineral and energy resources to comprise all materials, including those only surmised to exist, that have present or anticipated future value.

**Resource.**-A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.

**Original Resource.** - The amount of a resource before production.

**Identified Resources.** - Resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence. *Identified resources* include economic, marginally economic, and subeconomic components. To reflect varying degrees of geologic certainty, these economic divisions can be subdivided into *measured, indicated, and inferred*. (The terms "proven," "probable," and "possible", which are commonly used by industry in economic evaluations of ore or mineral fuels in specific deposits or districts, have been loosely interchanged with the terms *measured, indicated, and inferred*. The former terms are not a part of this **classification** system.)

**Demonstrated.** - A term for the sum of *measured plus indicated*.

**Measured.** - Quantity is computed from dimensions revealed in outcrops, trenches, workings, or drill holes; grade and(or) quality are computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are spaced so closely and the geologic character is so well defined that size, shape, depth, and mineral content of the resource are well established.

**Indicated.** - Quantity and grade and(or) quality are computed from information similar to that used for measured resources, but the sites for inspection, sampling, and measurement are farther apart or are otherwise less adequately spaced. The degree of assurance, although lower than that for measured resources, is high enough to assume continuity between points of observation.

**Inferred.** - Estimates are based on an assumed continuity beyond measured and(or) indicated resources, for which there is geologic evidence. *Inferred resources* may or may not be supported by samples or measurements.

**Reserve Base.** - That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The *reserve base* is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The *reserve base* includes those resources that are currently economic (*reserves*), marginally economic (*marginal reserves*), and some of those that are currently subeconomic (*subeconomic resources*). The term "geologic reserve" has been applied by others generally to the *reserve-base* category, but it also may include the *inferred-reserve-base* category; it is not a part of this **classification** system.

**Inferred Reserve Base.** - The in-place part of an identified resource from which inferred reserves are estimated. Quantitative estimates are based largely on knowledge of the geologic character of a deposit and for which there may be no samples or measurements. The estimates are based on an assumed continuity beyond the reserve base, for which there is geologic evidence.

**Reserves.** - That part of the reserve base which could be economically extracted or produced at the time of determination. The term *reserves* need not signify that extraction facilities are in place and operative. *Reserves* include only recoverable materials; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this **classification** system.

**Marginal Reserves.** - That part of the reserve base which, at the time of determination, borders on being economically producible. Its essential characteristic is economic uncertainty. Included are resources that would be producible, given postulated changes in economic or technologic factors.

**Economic.** - This term implies that profitable extraction or production under defined investment assumptions has been established, analytically demonstrated, or assumed with reasonable certainty.

**Subeconomic Resources.** - The part of identified resources that does not meet the economic criteria of reserves and marginal reserves.

**Undiscovered Resources.** - Resources, the existence of which are only postulated, comprising deposits that are separate from identified resources. *Undiscovered resources* may be postulated in deposits of such grade and physical location as to render them economic, marginally economic, or subeconomic. To reflect varying degrees of geologic certainty, undiscovered resources may be divided into two parts:

**Hypothetical Resources.** - Undiscovered resources that are similar to known mineral bodies and that may be reasonably expected to exist in the same producing district or region under analogous geologic conditions. If exploration confirms their existence and reveals enough information about their quality, grade, and quantity, they will be reclassified as identified resources.

**Speculative Resources.** - Undiscovered resources that may occur either in known types of deposits in favorable geologic settings where mineral discoveries have not been made, or in types of deposits as yet unrecognized for their economic potential. If exploration confirms their existence and reveals enough information about their quantity, grade, and quality, they will be reclassified as identified resources.

**Restricted Resources/Reserves.** - That part of any **resource/reserve** category that is restricted from extraction by laws or regulations. For example, restricted reserves meet all the requirements of reserves except that they are restricted from extraction by laws or regulations.

### **Guidelines for Classification of Mineral Resources**

1. All naturally occurring metals, nonmetals, and fossil fuels in sufficient concentration can be classified in one or more of the categories.
2. Where the term *Reserves* is used alone, without a modifying adjective such as indicated, marginal, or inferred, it is to be considered synonymous with the demonstrated-economic category, as shown in figure 1.
3. Definitions of resource categories can be modified for a particular commodity in order to conform with accepted usage involving special **geological** and engineering characteristics. Such modified definitions for particular commodities will be given in forthcoming government publications.
4. Quantities, qualities, and grades may be expressed in different terms and units to suit different purposes, but usage must be clearly stated and defined.
5. The geographic area to which any **resource/reserve** estimate refers must be defined.
6. All estimates must show a date and author.
7. The *reserve base* is an encompassing resource category delineated by physical and chemical criteria. A major purpose for its recognition and appraisal is to aid in long-range public and commercial planning. For most mineral commodities, different grades and tonnages, or other appropriate resource parameters, can be specified for any given deposit or area, or for the Nation, depending on the specific objectives of the estimators; therefore, the position of the lower boundary of the reserve base, which extends into the subeconomic category, is variable, depending on those objectives. The intention is to

define a quantity of in-place material, any part of which may become economic, depending on the extraction plans and economic assumptions finally used. When those criteria are determined, the initial reserve-base estimate will be divided into three component parts: reserves, marginal reserves, and a remnant of subeconomic resources. For the purpose of Federal commodity assessment, criteria for the reserve base will be established for each commodity.

8. *Undiscovered resources* may be divided in accordance with the definitions of *hypothetical* and *speculative resources*, or they may be divided in terms of relative probability of occurrence.

9. *Inferred reserves* and the *inferred reserve base* are postulated extensions of reserves and of the reserve base. They are identified resources quantified with a relatively low degree of certainty. Postulated quantities of resources not based on reserve/reserve-base extensions, but rather on geologic inference alone, should be classified as undiscovered.

10. Locally, limited quantities of materials may be produced, even though economic analysis has indicated that the deposit would be too thin, too low grade, or too deep to be classified as a reserve. This situation might arise when the production facilities are already established or when favorable local circumstances make it possible to produce material that elsewhere could not be extracted profitably. Where such production is taking place, the quantity of in-place material shall be included in the reserve base, and the quantity that is potentially producible shall be included as a reserve. The profitable production of such materials locally, however, should not be used as a rationale in other areas for classifying as reserves, those materials that are similar in thickness, quality, and depth.

11. Resources classified as reserves must be considered economically producible at the time of **classification**. Conversely, material not currently producible at a profit cannot be classified as reserves. There are situations however, in which mining plans are being made, lands are being acquired, or **mines** and plants are being constructed to produce materials that do not meet economic criteria for reserve **classification** under current costs and prices, but would do so under reasonable future expectations. For some other materials, economic producibility is uncertain only for lack of detailed engineering assessment. The marginal reserves category applies to both situations. When economic production appears certain for all or some of a marginal reserve, it will be reclassified as reserves.

12. Materials that are too low grade or for other reasons are not considered potentially economic, in the same sense as the defined resource, may be recognized and their magnitude estimated, but they are not classified as resources. A separate category, labeled *other occurrences*, is included in figures 1 and 2.

13. In figure 1, the boundary between *subeconomic* and *other occurrences* is limited by the concept of *current or potential feasibility of economic production*, which is required by the definition of a resource. The boundary is obviously uncertain, but limits may be specified in terms of grade, quality, thickness, depth, percent extractable, or other economic-feasibility variables.

14. Varieties of mineral or energy commodities, such as bituminous coal as distinct from lignite, may be separately quantified when they have different characteristics or uses.

15. The amount of past cumulative production is not, by definition, a part of the resource. Nevertheless, a knowledge of what has been produced is important to an understanding of current resources, in terms of both the amount of past production and the amount of residual or remaining in-place resource. A separate space for cumulative production is shown in figure 1. Residual material left in the ground during current or future extraction should be recorded in the resource category appropriate to its economic-recovery potential.

16. In classifying reserves and resources, it is necessary to recognize that some **minerals** derive their economic viability from their coproduct or byproduct relationships with other **minerals**. Such relationships must be clearly explained in footnotes or in an accompanying text.

17. Considerations other than economic and geologic, including legal, regulatory, environmental, and political, may restrict or prohibit the use of all or part of a deposit. Reserve and resource quantities known to be restricted should be recorded in the appropriate **classification** category; the quantity restricted and the reason for the restriction should be noted.

18. The **classification** system includes more divisions than will commonly be reported or for which data are available. Where appropriate, divisions may be aggregated or omitted.

19. The data upon which resource estimates are based and the methods by which they are derived are to be documented and preserved.

Figure1. Major Elements of Mineral-Resource Classification, Excluding *Reserve Base* and *Inferred Reserve Base* Resources of (commodity name)

[A part of reserves or any resource category may be restricted from extraction by laws or regulations (see text)]  
 Area: (mine, district, field, state, etc.) Unit: (tons, barrels, etc.)

Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range	
	Measured	Indicated		Hypothetical (or)	Speculative
ECONOMIC	<b>Reserves</b>		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUBECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		
Other Occurrences	Includes nonconventional and low-grade materials				

Figure2. *Reserve Base* and *Inferred Reserve Base* Classification Categories

Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range	
	Measured	Indicated		Hypothetical (or)	Speculative
ECONOMIC	Reserve Base		Inferred Reserves		
MARGINALLY ECONOMIC			Base		
SUBECONOMIC					
Other Occurrences	Includes nonconventional and low-grade materials				

### 2.3.2. Various approaches to depletion

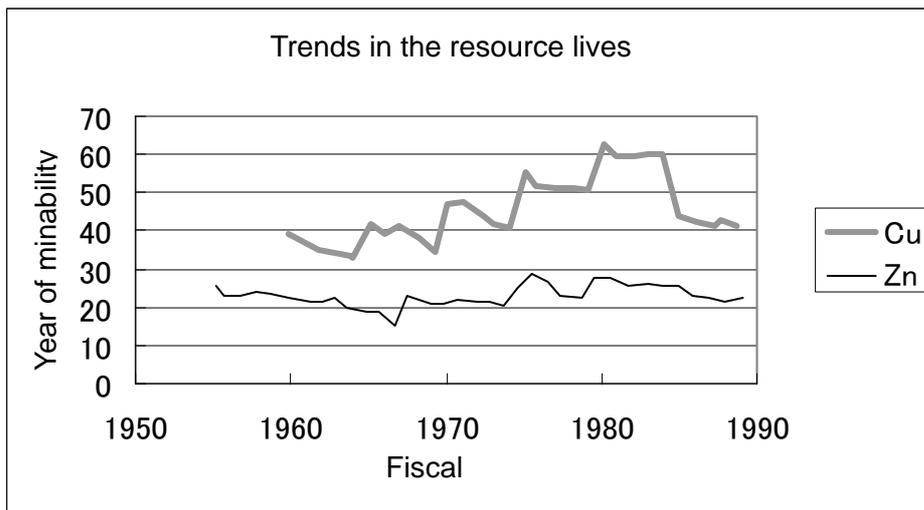
#### (1) Year of minability

The life of a mineral resource (i.e., the number of year an energy resource can be extracted) can be derived with the following equation:

$$\text{Year of minability} = \frac{\text{Resource reserves}}{\text{Annual consumption of resource.}}$$

This value is always derived from the above formula; a value of 30 does not mean that the resource would be depleted in 30 years.

The following figure shows trends in the resource lives of copper and zinc. In simple terms, a resource life of 40 years for copper in 1960 would equate to the resource life of 10 years in 1990, and the resource would be depleted in 2000. However, in actuality, copper is still in ample supply even after 2000, so during those 40 years the life of resource increased. This resulted from the discovery of new copper mines, etc., with reserves increasing even as production increases. In the case of zinc, the resource life went from about 20 years to about 30 years; in other words, it looks like a new mine was developed so that the resource would not reach depletion in 20 years.



As we can see in the figure above, the resource life does not directly express depletion. It cannot be a value that reflects whether the resource life should be maintained at the 20-year level or at the 100-year level, but we must not overlook the fact that it means the degree of importance of depletion.

#### (2) Ratio of extraction

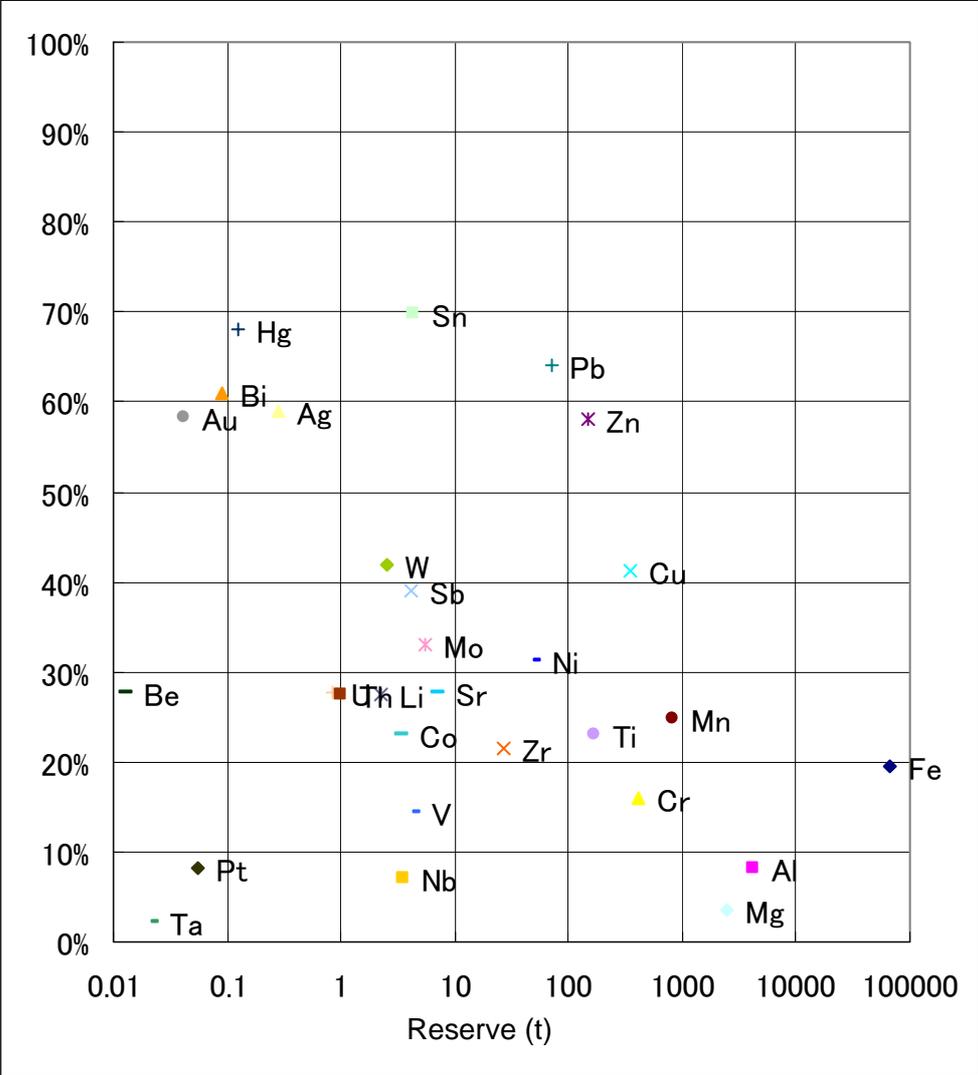
This refers not to reserves, but is a comparison between the amount of resources that have already been consumed, and the amount that still exists as reserves. In other words,

$$\text{Ratio of extraction} = \frac{\text{Amount extracted}}{\text{Reserves} + \text{Amount extracted.}}$$

The following figure shows the relation between the excavation rate and the reserve. Some resources like mercury and tin have already been extracted at a rate of 60-70%.

Although it is necessary to accumulate records about the ratio of extraction from long ago, much

if not most of the data reflects use in recent years, at which point relatively objective data have been obtained. However, as with the case of resource life, the amount of reserve changes over the years, so the ratio of extraction does not express the objective rate of resource consumption.

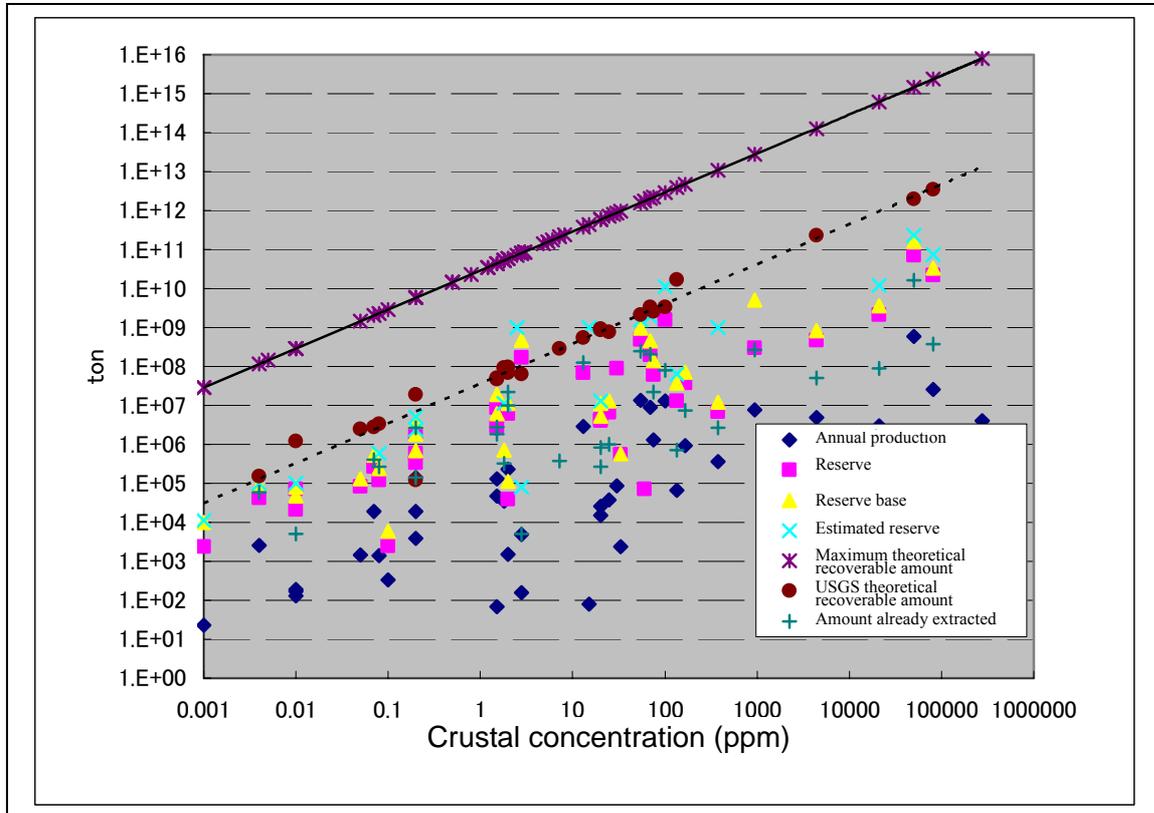


(3) Amount of ultimately usable resources

In contrast to the year of minability which can fluctuate from year to year, the absolute amount of resources is estimated, and by knowing the time to that point, the depletion of that resource can be discussed. The figure below shows the ratio of occurrence (ppm) in the crust (called the Clarke number) for each element component plotted against the proven reserves, annual production, amount already extracted (excavated), and so on. The \* in the top of the diagram and associated line show examples of calculated reserves of usable resources based on the Clarke number of each element (Akira Takada: Global Resource Strategy Notebook, published by Hakua Shobo, 1994, p. 44). Here, overburden operations on the surface and excavations inside the mine bring the minable depth down to 300 m, which is set as a crust thickness of 1/100, and the estimated amount of useable resources is  $2.9 \times 10^{16}$  tons. Multiplying that amount by the crustal concentration (ppm) allows us to calculate the ultimate usable limit for each resource.

In contrast, the USGS has calculated the “theoretical recoverable amount” down to a depth of 1000 m based on current prices and plotted it on the  $4 \times 10^7 \times$  Crustal concentration (ppm) shown by

the dotted line. The upper limits of the estimated resources, reserve base, etc., are in this order. It is clear that what we can acknowledge as resources do not even reach the 1% level (ultimate usable limit) in the earth's crust.

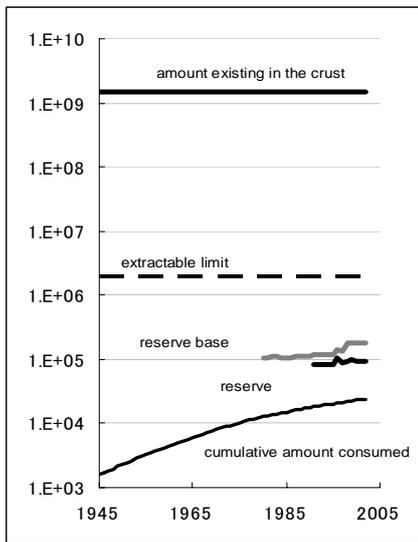


While there are some people who maintain that the *law of the conservation of matter* means that mineral resources will never be exhausted, but the resources that we are dealing with exist in amounts that do not even reach 0.1% of the matter in the earth's crust. The use and disposal of these resources is an act of diluting the elements into non-target resources.

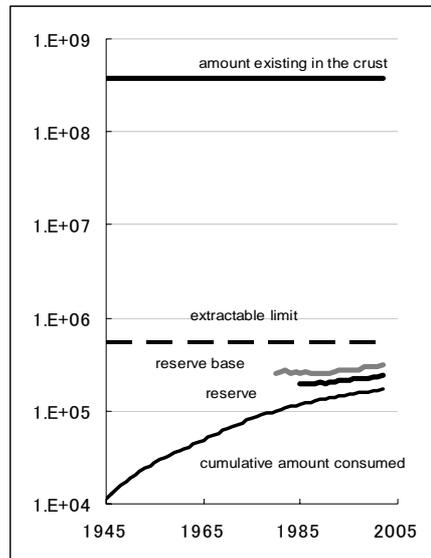
In this way, the resources that we use are in components that are thinly distributed in the crust and oceans in limited concentrations of about 1/1000, and it is almost meaningless to discuss the theoretical upper limit as an absolute value in the crust and oceans. Some sort of subjective way to make decisions must be introduced to calculate the amount of useable resources. However, the USGS's theoretical recoverable amount is related to the upper levels of reserve base, reserve amount, etc., and is closely related to linearity vis-a-vis the amount existing in the crust. Therefore, when making a comparative assessment among resources, it may be more effective to use the concentration existing in the crust.

In addition, the following figure shows annual changes in relatively low depletability iron and relatively high depletability lead in terms of ultimate useable limit (amount existing in the crust), the extractable limit (USGS theoretical recoverable amount), the reserve base, the reserve amount, and the cumulative amount consumed (already extracted). In the case of iron, there is a large gap between the extractable amount on the one hand and the reserve base or reserve amount on the other, and there are large differences in cumulative consumption. However, in the case of lead the gaps among these 4 factors are small, demonstrating that the reserve amount and reserve base will in all likelihood be undergoing intensive pressure from cumulative consumption.

Fe



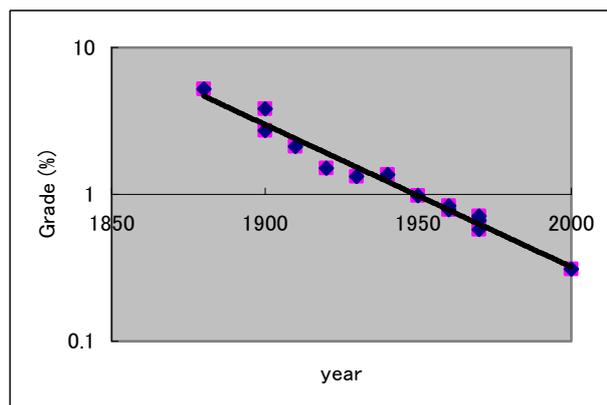
Pb



(4)

#### Deterioration of quality as a depletion concept

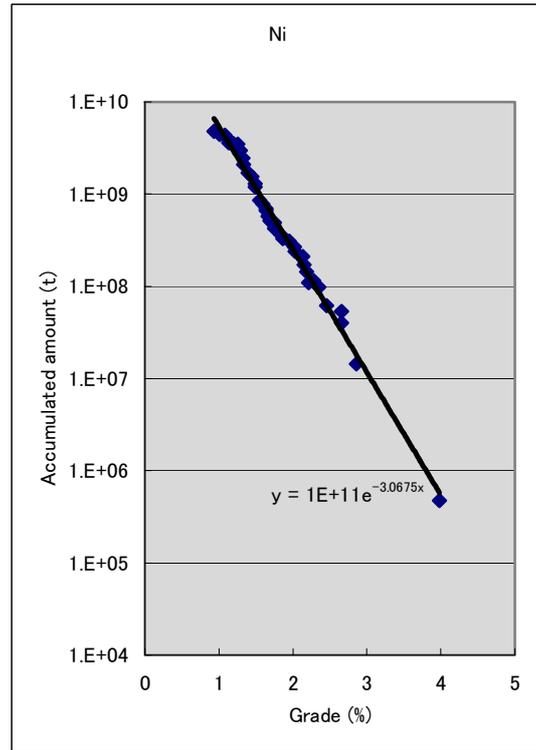
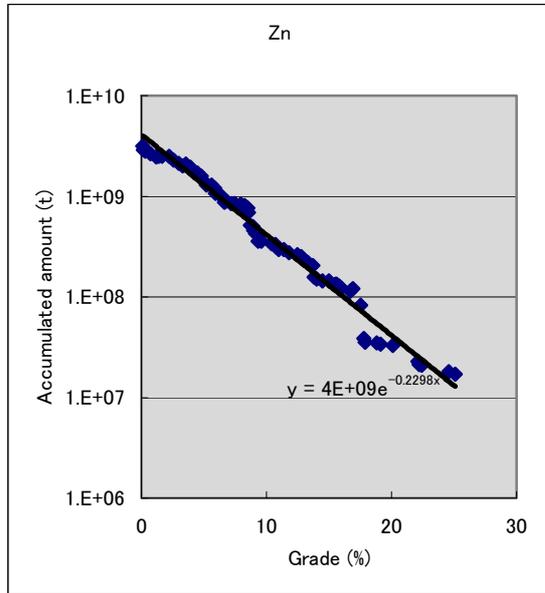
Some researchers believe that the depletion level of a resource should not be considered as changes in the amount but as changes in quality. The figure shows changes in the grade of copper ore. As the resource is depleted, the easily extracted high-grade copper ore veins are exhausted, making it necessary to extract the low-grade ores. Ultimately, the economic return cannot be maintained, meaning that depletion is approaching. In the case of copper, the grade of ore has decreased by one decimal place in the past century.



When discussing this situation, it is necessary to know about annual changes in grade at each mine. Therefore, there is demand for existing data to be publicly released and accumulated, but it is difficult to investigate all resources.

T. Shoji et al. discussed the depletion levels of resources based on minability distributions of the present mines (T. Shoji: MMIJ/IMM Joint Symposium, Kyoto 1989). The following figures show semilogarithmic relations between grades and amounts accumulated from higher grade side for zinc

and nickel deposits.



When the reserve amount and the accumulated amount for grade of  $x$  % are  $T(x)$  and  $t(x)$  respectively, the following relation is obtained,

$$T(x) = \int_x^{\infty} t(x) dx$$

$$= C \cdot \exp(-bx)$$

where  $C$  and  $b$  are constants determined by mineral ores.

From this equation, the reserve amount  $t(x)$  and the metal amount  $m(x)$  obtained from multiplication of the reserve amount and its grade are as follows:

$$t(x) = \frac{dT(x)}{dx}$$

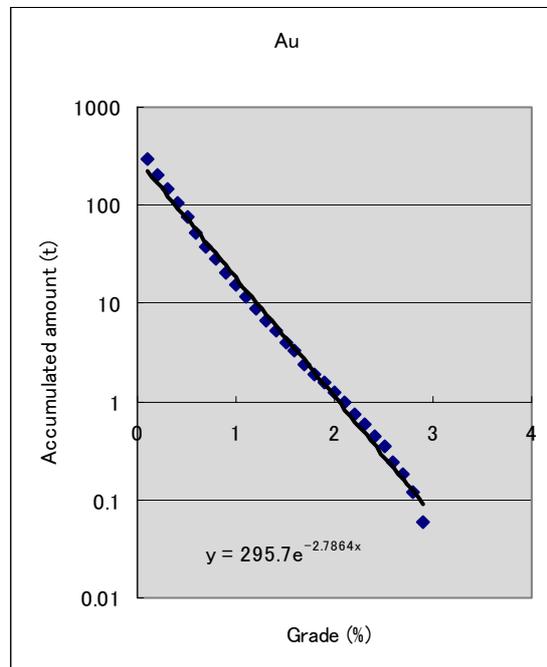
$$= C \cdot b \cdot \exp(-bx)$$

$$m(x) = x \cdot t(x)$$

$$= C \cdot b \cdot x \cdot \exp(-bx)$$

Thus the curve of  $m(x)$  shows maximum. This means that a produced metal amount increases until  $x = 1/b$  with decreasing of the grade by developing a deposit, but that the amount decreases for  $x$  values less than  $1/b$  even though the grade decreases. It is found that there is a critical value of grade. Therefore it is theoretically impossible to excavate the same metal amount under the same economic condition for lower grades than the critical values. The critical values of grade are 4.3% for zinc and 0.31% for nickel. The following figure shows a similar curve for gold. In the case of gold, the critical value of grade is 0.36 g/t ( $= 1/2.786$ ).

It is difficult to generalize the discussion, however it is necessary to accumulate deposit data for exhibiting that depletions can be scientifically discussed.



### 3. Data Regarding Sustainability of Mineral Resources

#### 3.1. Various Data

There are many survey reports concerning depletions of resources, however, only a few parts of them are based on data. The following database groups are relatively reliable:

##### (1) Mineral Commodity Summaries

- 1) Web site: <http://minerals.usgs.gov/minerals/pubs/mcs/>
- 2) Publisher: U.S. Department of the Interior, U.S. Geological Survey
- 3) Objective (Listed) elements, etc.: 90 elements and minerals
- 4) Circulation period: Annual  
Minerals Yearbook (annual), and Mineral Industry Surveys (quarter)
- 5) Free or non-free charge: Free
- 6) Features, etc.: Most reliable database, but some elements or minerals do not contain their reserve data.

##### (2) Minerals Handbook 2000-2001

- 1) Web site: <http://www.mining-journal.com/indexbooks.htm>
- 2) Publisher: Mining Journal Books Ltd.
- 3) Objective (Listed) elements, etc.: 52 elements and minerals
- 4) Circulation period: Once per 2 years
- 5) Free or non-free charge: Non-free

##### (3) World Metal Statistics Yearbook

- 1) Web site: <http://www.world-bureau.com/site.html>
- 2) Publisher: World Bureau of Metal Statistics (WBMS)
- 3) Objective (Listed) elements, etc.:

- 4) Circulation period:  
 5) Free or non-free charge: Non-free

(4) Who owns who in Mining 2001

- 1) Web site: <http://www.rmg.se>
- 2) Publisher: Raw Materials Group Stockholm/Roskill Information Services. Ltd.
- 3) Objective (Listed) elements, etc.: 22 elements and minerals (no data of reserve and production amounts in the world)
- 4) Circulation period: Final issue at 2001?
- 5) Free or non-free charge: Non-free
- 6) Features, etc.: No data of reserve amounts, data of relationships between global major producers and oligopoly conditions, company product amounts, etc.

(5) Roskill Metals and Minerals Reports

- 1) Web site: <http://www.roskill.com/>
- 2) Publisher: Roskill Consulting Group
- 3) Objective (Listed) elements, etc.: 62 elements and materials
- 4) Circulation period: Irregular
- 5) Free or non-free charge: Non-free
- 6) Features, etc.:
  - Some material data do not contain reserves/resources items, and there is no data of antimony and tantalum.
  - Search of chapters and sections are available.

Listed conditions of reserve data in these database groups are summarized in the following table mainly based on the Mineral Commodity Summaries.

Table Database group containing reserve dat

USGS		Roskill		Raw Materials Data	
Abrasives, Manufactured	○				
		Activated Carbon	○		
Aluminum	○				
Antimony	⊙				
Arsenic	⊙				
Asbestos	⊙				
Barite	⊙				
Bauxite and Alumina	⊙				
		Bentonite	○		
Beryllium	⊙				
Bismuth	⊙				
Boron	⊙				
Bromine	⊙				
Cadmium	⊙				
		Calcium; see 2 reports under written			
Cement	○				
Cesium	⊙				
Chromium	⊙				
Clays	⊙				
Cobalt	⊙				○
Columbium(Niobium)	⊙				

Copper	⊙				○
Diamond, Industrial	⊙				○
Diatomite	⊙				
Feldspar	○				
Fluospar	⊙				
Gallium	○				
Garnet, Industrial	⊙				
Gemstones	○				
Germanium	⊙				
Gold	⊙				○
Graphite, Natural	⊙				
		Ground Calcium Carbonate	⊙		
Gypsum	⊙	Gypsum & Anhydrite	⊙		
(Hafnium)	⊙				
Helium	⊙				
Ilmenite	⊙				
Indium	⊙				
Iodine	⊙				
Iron Ore	⊙				○
Iron and Steel	○				
Iron and Steel Scrap	○				
Iron and Steel Slag	○				
		Kaolin	⊙		
Kyanite and Related Minerals	⊙				
Lead	⊙				○
Lime	⊙				
Lithium	⊙				
Magnesium, Compounds & Metal	⊙				○
Manganese	⊙				○
Manufactured Abrasives	○				
Mercury	⊙				
Mica	⊙				
Molybdenum	⊙				
Nickel	⊙				○
Niobium (See Columbium)	⊙				○
Nitrogen (Fixed), Ammonia	○				
		Olivine	⊙		
Peat	⊙				
Perlite	⊙				
		Petroleum Coke	○		
Phosphate Rock	⊙				
Platinum-Group Metals	⊙				○
Potash	⊙				
		Precipitated Calcium Carbonate	○		
Pumice and Pumicite	⊙				
Quartz Crystal, Industrial	○				
Rare Earths	⊙				○
Rhenium	⊙				
Rubidium	⊙				
Rutile	⊙				
Salt	⊙				

Sand and Gravel, Construction	○				
Sand and Gravel, Industrial	○				
Scandium	○				
Selenium	⊙				
Silicon	○	including Ferrosilicon	⊙		
Silver	⊙				○
Soda Ash	⊙				
Sodium Sulphate	⊙				
Stone, Crushed	○				
Stone, Dimension	○				
Strontium	⊙				
Sulfur	○				
Talc and Pyrophyllite	⊙				
Tantalum	⊙				
Tellurium	⊙				
Thallium	⊙				
Thorium	⊙				
Tin	⊙				
Titanium and Titanium Dioxide	⊙				○
Tungsten	⊙				
				Uranium	○
Vanadium	⊙				○
Vermiculite	⊙				
		Wollastonite	○		
Yttrium	⊙				
		Zeolites	⊙		
Zinc	⊙				○
Zirconium including Hafnium	⊙				

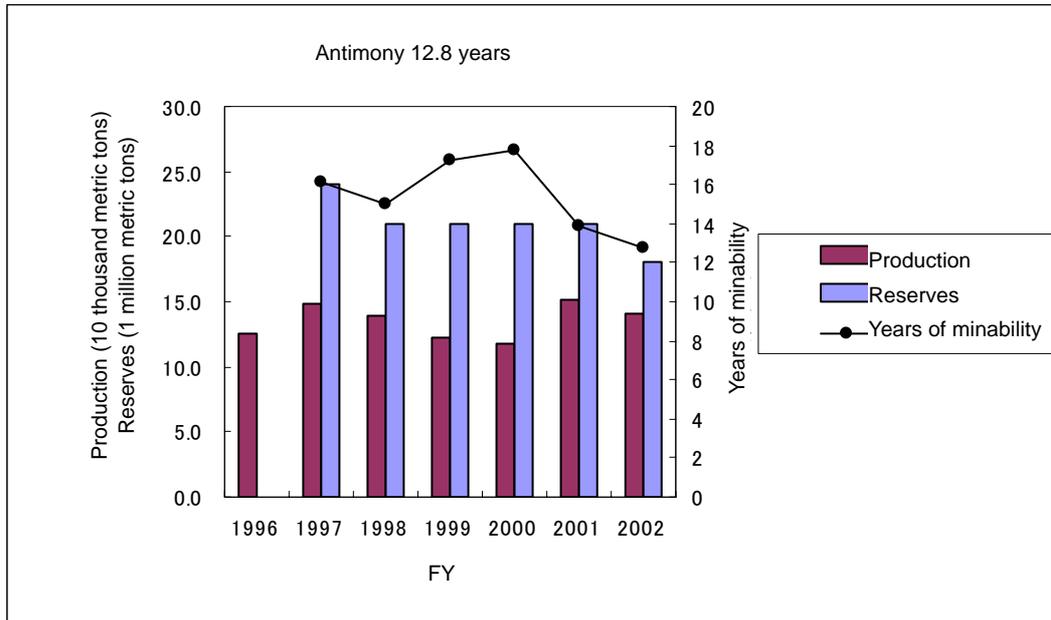
Note: ⊙= Data available, ○= No data available

### 3.2 Depletion Data for Each Type of Ore

The data were collected and arranged from the USGS' Mineral Commodity Summaries, the most popular, transparent and reliable source. Industrial statistics included not only changes in yearly production, but also changes in reserves from one fiscal year to another. Some of the reports for statistical target countries are missing, and closer examination revealed some major discrepancies in definitions used in different countries. Therefore, the statistics were not listed simply by fiscal year, and all of them were taken from the web site of Mineral Commodity Summaries.

The table lists production and reserves by fiscal year, reserve base by fiscal year in the case of reevaluations, etc., and items for resources were generally listed for "resources" in the text. Most of the units are "metric tons," but some of these are for 1000-ton and million-ton units, and are listed in the table as such. In the graphs, the fiscal years are shown on the x-axis, while production and reserves are shown in the y-axis (left side) with bar graphs at different scales. In addition, the life of resources, which was derived from simple calculations from these data, are shown by the broken line graph in the y-axis (right side). The number of years listed to the right of the resource name in the figures denotes the life of the respective resource derived from FY 2002 data.

Sb Antimony

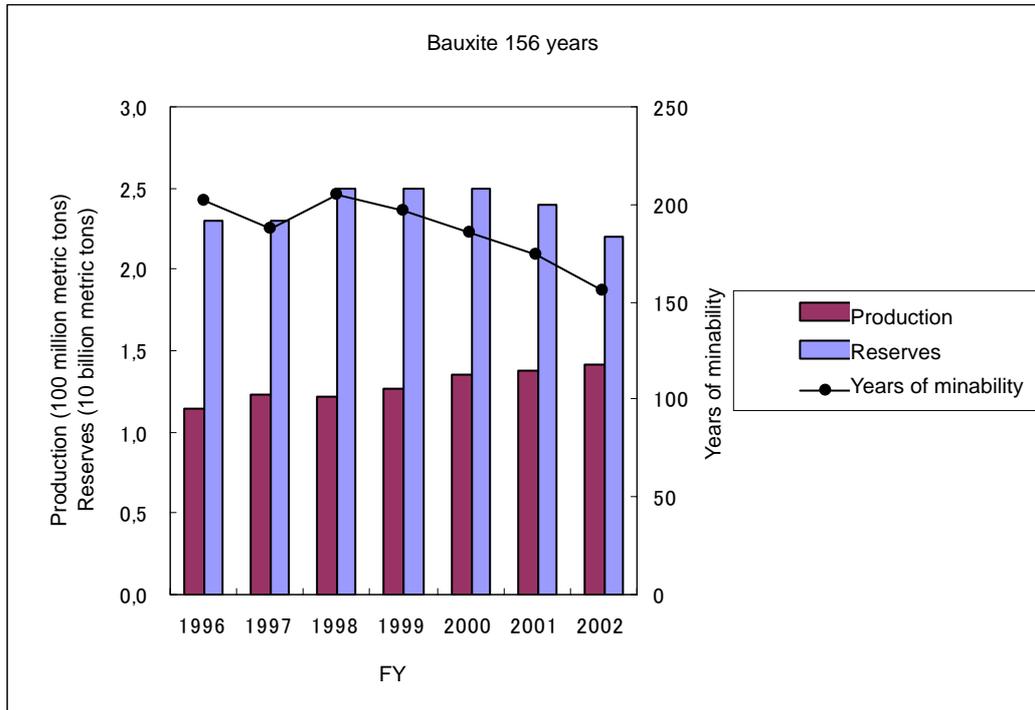


Year	Antimony production (t)	Reserves (t)	Reserve base (t)	Resources (t)
1995	103,000			
1996	126,000	NA	NA	5,100,000
1997	149,000	2,400,000	3,600,000	
1998	140,000	2,100,000	3,200,000	
1999	122,000	2,100,000	3,200,000	
2000	118,000	2,100,000	3,200,000	
2001	151,000	2,100,000	3,200,000	
2002	141,000	1,800,000	3,900,000	

As Arsenic

	Arsenic			
Year	Production (t)	Reserves	Reserve base	Resources (t)
1995	41,000		20-30 times	
1996	42,000			
1997	41,000			
1998	40,800			11,000,000
1999	38,800			11,000,000
2000	33,900			11,000,000
2001	35,500			
2002	35,000			

Al Aluminum (Bauxite)

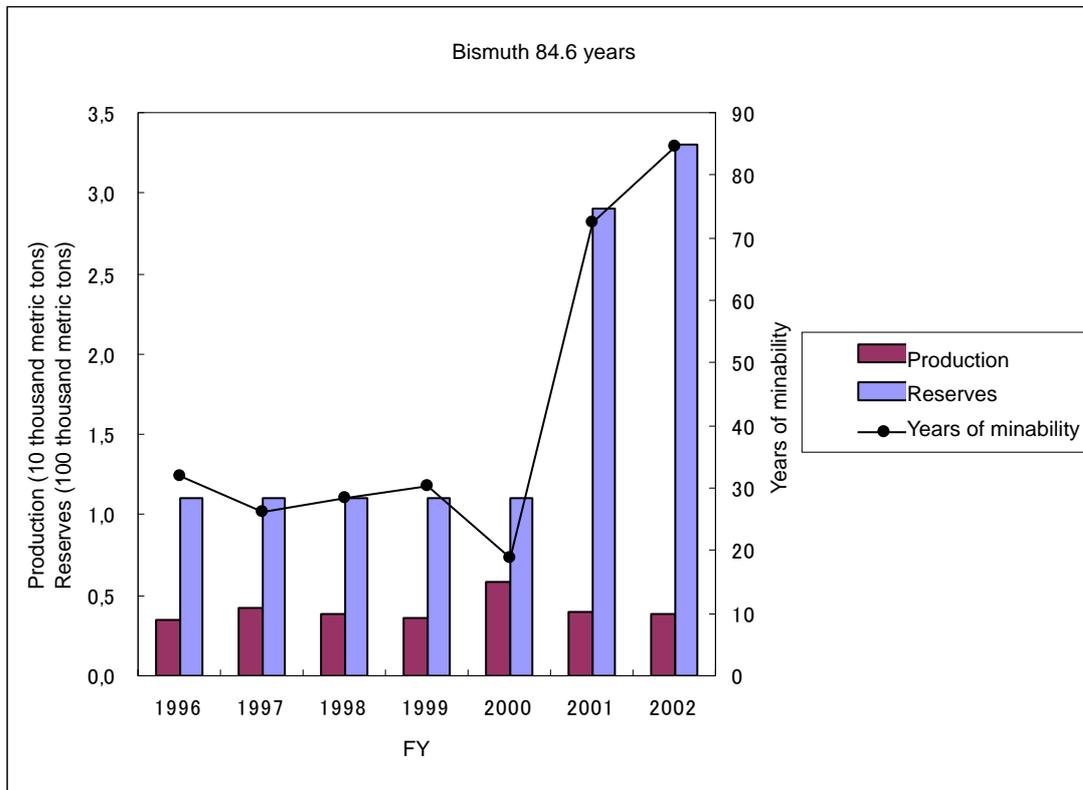


	Bauxite			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year				
1995	109,000			
1996	114,000	23,000,000	28,000,000	55-75 billion
1997	123,000	23,000,000	28,000,000	
1998	122,000	25,000,000	34,000,000	
1999	127,000	25,000,000	34,000,000	
2000	135,000	25,000,000	35,000,000	
2001	138,000	24,000,000	34,000,000	
2002	141,000	22,000,000	33,000,000	

Be Beryllium

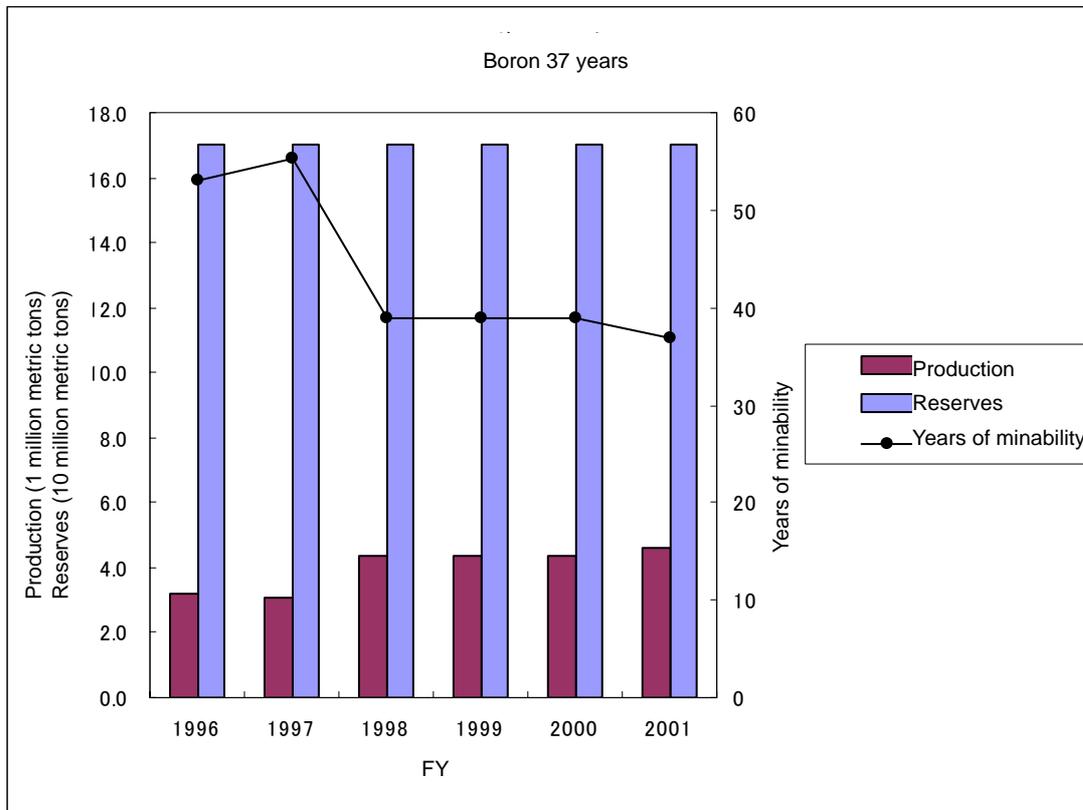
	Beryllium			
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year				
1995	327			
1996	336			
1997	331			
1998	344			
1999	301			
2000	280			80,000
2001	160			
2002	160			

Bi Bismuth



	Bismuth			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year	Content			
1995	3,040			
1996	3,440	110,000	250,000	
1997	4,210	110,000	260,000	
1998	3,880	110,000	260,000	
1999	3,620	110,000	260,000	
2000	5,880	110,000	260,000	
2001	4,000	290,000	690,000	
2002	3,900	330,000	680,000	

## B Boron

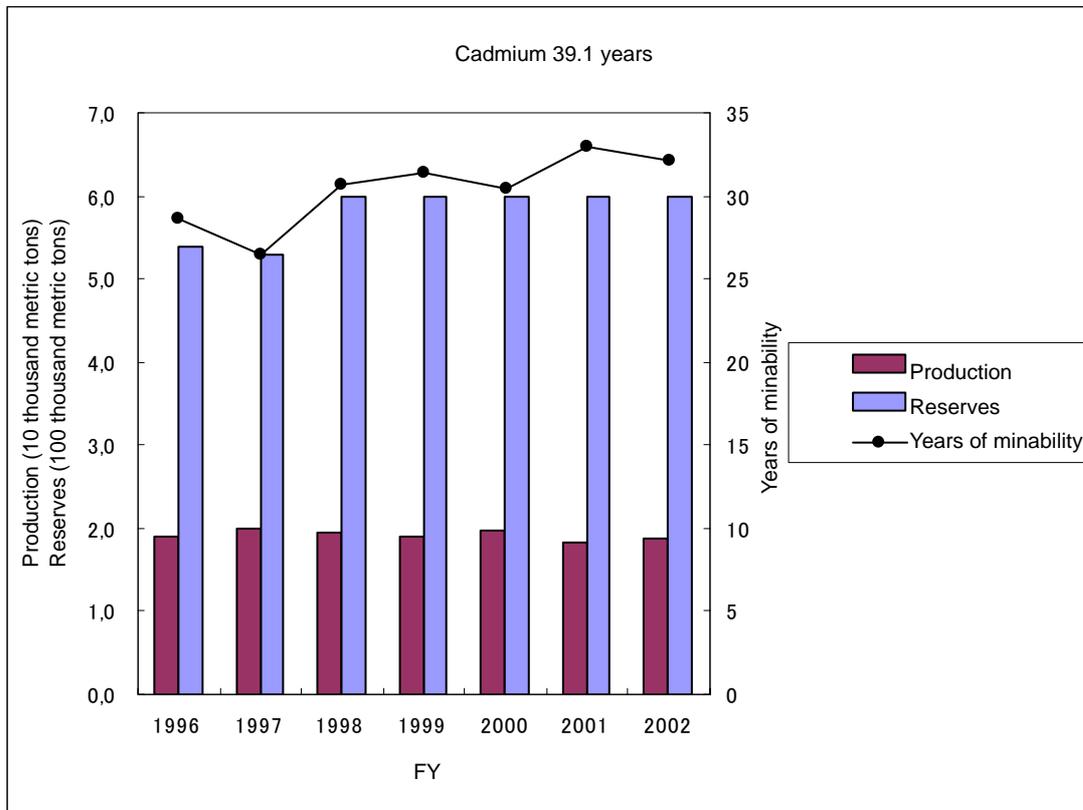


	Boron			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources
Year	B <sub>2</sub> O <sub>3</sub>			
1995	2,400			
1996	3,200	170,000	420,000	
1997	3,070	170,000	470,000	
1998	4,370	170,000	470,000	
1999	4,370	170,000	470,000	
2000	4,370	170,000	470,000	
2001	4,600	170,000	470,000	
2002	4,800	Large	Large	

Br Bromine

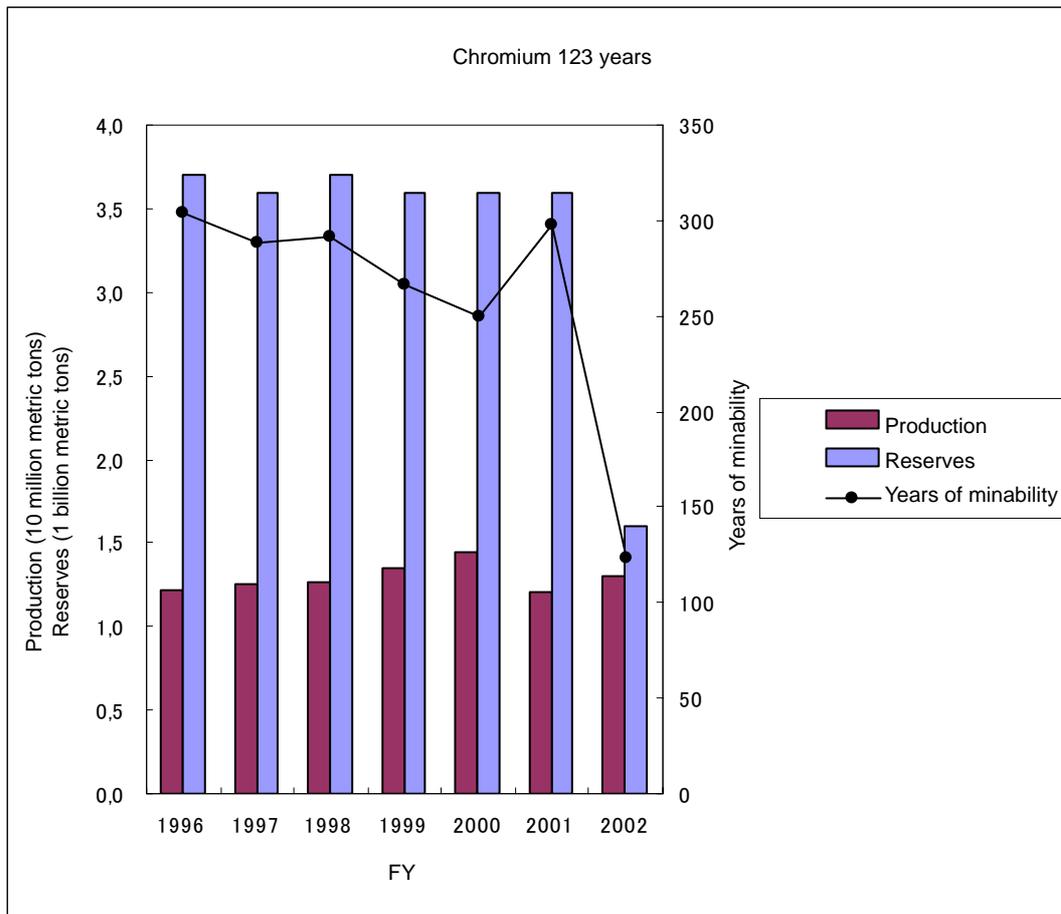
	Bromine			
	Production (1000 t)	Reserves	Reserve base	Resources (t)
Year	Content			
1995	430			
1996	450	NA	NA	1 billion
1997	470	NA	NA	Sea water 100 trillion
1998	510	NA	NA	
1999	530	NA	NA	
2000	542	NA	NA	
2001	540	NA	NA	
2002	550	NA	NA	

Cd Cadmium



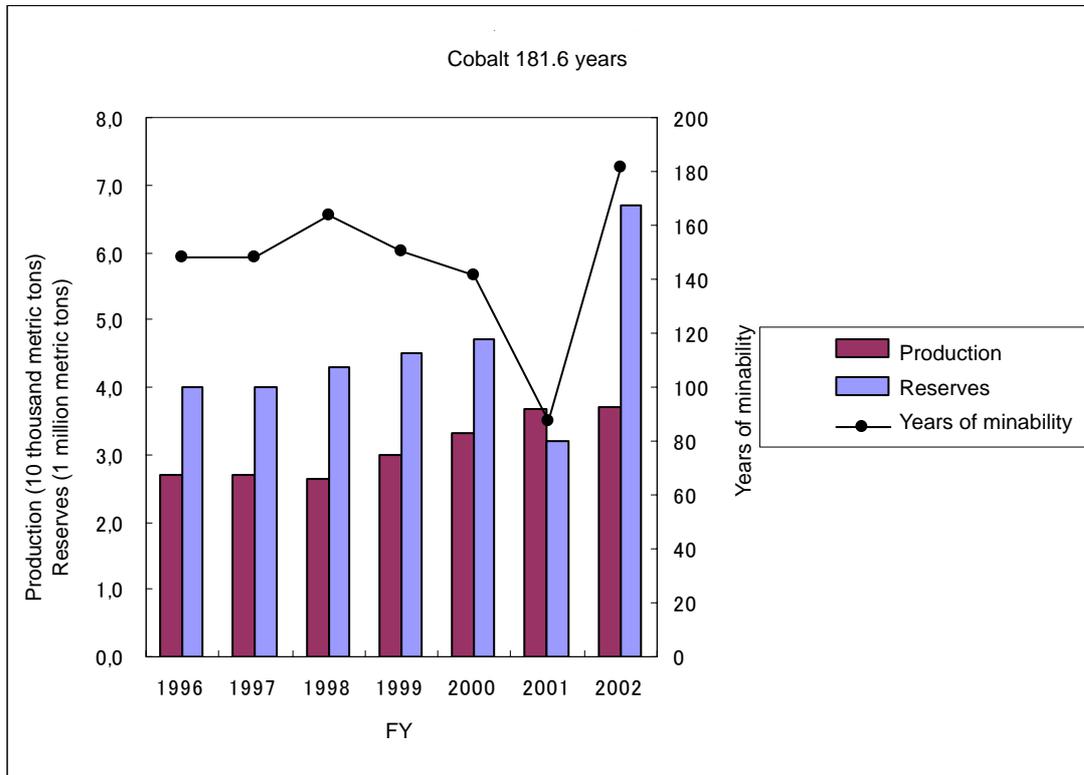
	Cadmium			
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year	Content			
1995	18,500			
1996	18,900	540,000	970,000	0.3% of Zn
1997	20,000	530,000	1,000,000	0.3*6 million
1998	19,600	600,000	1,200,000	
1999	19,100	600,000	1,200,000	
2000	19,700	600,000	1,200,000	
2001	18,200	600,000	1,200,000	
2002	18,700	600,000	1,800,000	0.6 million

Cr Chromium



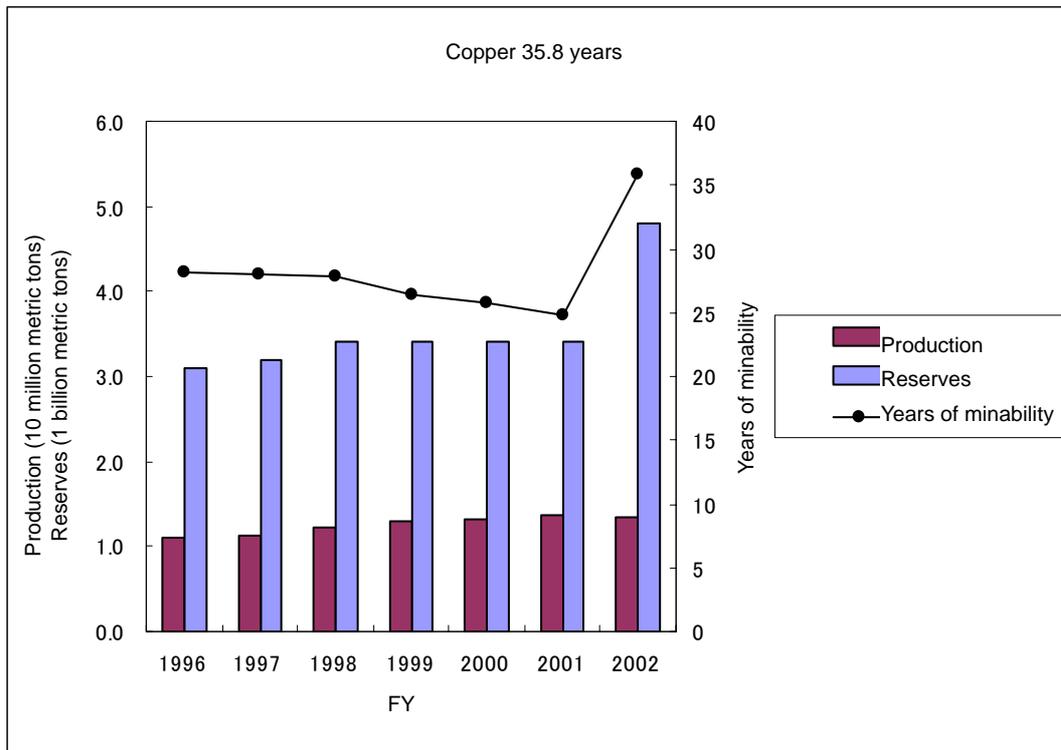
	Chromium			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year	Gross weight			
1995	12,000			
1996	12,190	3,700,000	7,500,000	11 billion
1997	12,500	3,600,000	7,500,000	
1998	12,700	3,700,000	7,600,000	
1999	13,500	3,600,000	7,500,000	
2000	14,400	3,600,000	7,600,000	
2001	12,100	3,600,000	7,600,000	
2002	13,000	1,600,000	7,100,000	

Co Cobalt



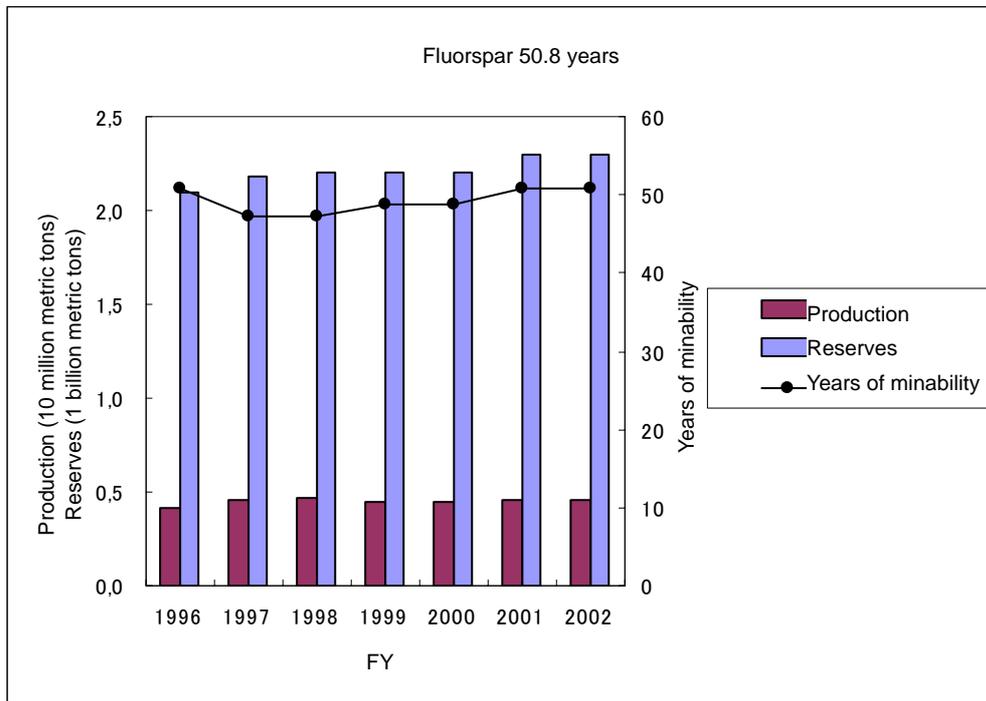
	Cobalt			
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year	Content			
1995	22,100			
1996	27,000	4,000,000	9,000,000	11 million
1997	27,000	4,000,000	9,000,000	
1998	26,300	4,300,000	9,500,000	
1999	29,900	4,500,000	9,600,000	
2000	33,300	4,700,000	9,900,000	
2001	36,700	3,200,000	10,000,000	
2002	36,900	6,700,000	13,000,000	

Cu Copper



Copper				
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year	Content			
1995	10,000			
1996	11,000	310,000	610,000	1.6 billion
1997	11,400	320,000	630,000	
1998	12,200	340,000	650,000	" +0.7 billion nodule"
1999	12,900	340,000	650,000	
2000	13,200	340,000	650,000	
2001	13,700	340,000	650,000	
2002	13,400	480,000	950,000	

## Fluorspar



	Fluorspar			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year				
1995	3,940			
1996	4,140	210,000	310,000	330 million
1997	4,620	218,000	371,000	
1998	4,670	220,000	370,000	
1999	4,510	220,000	370,000	
2000	4,520	220,000	380,000	
2001	4,530	230,000	440,000	
2002	4,530	230,000	480,000	

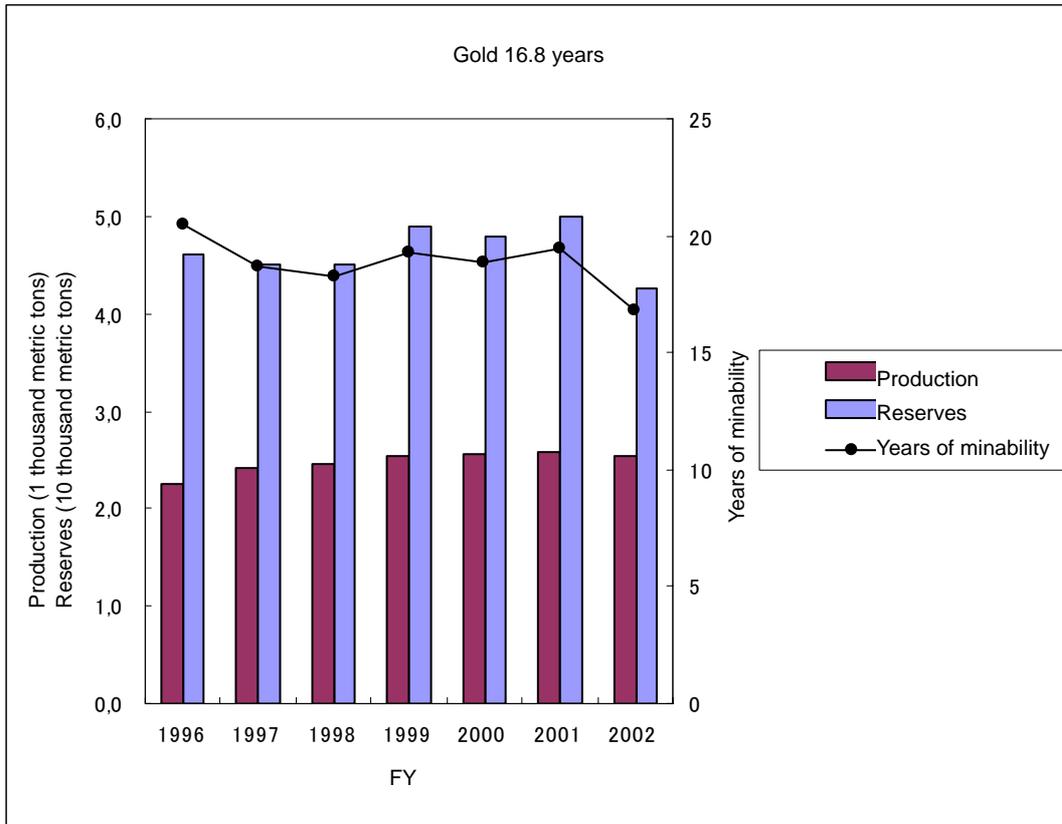
Ga Gallium

	Gallium			
	Production (kg)	Reserves	Reserve base	Resources (kg)
Year	Content			
1995				
1996	70,000			1 billion
1997	68,000			
1998	60,000			
1999	75,000			
2000	100,000			
2001	110,000			
2002	81,000			

Ge Germanium

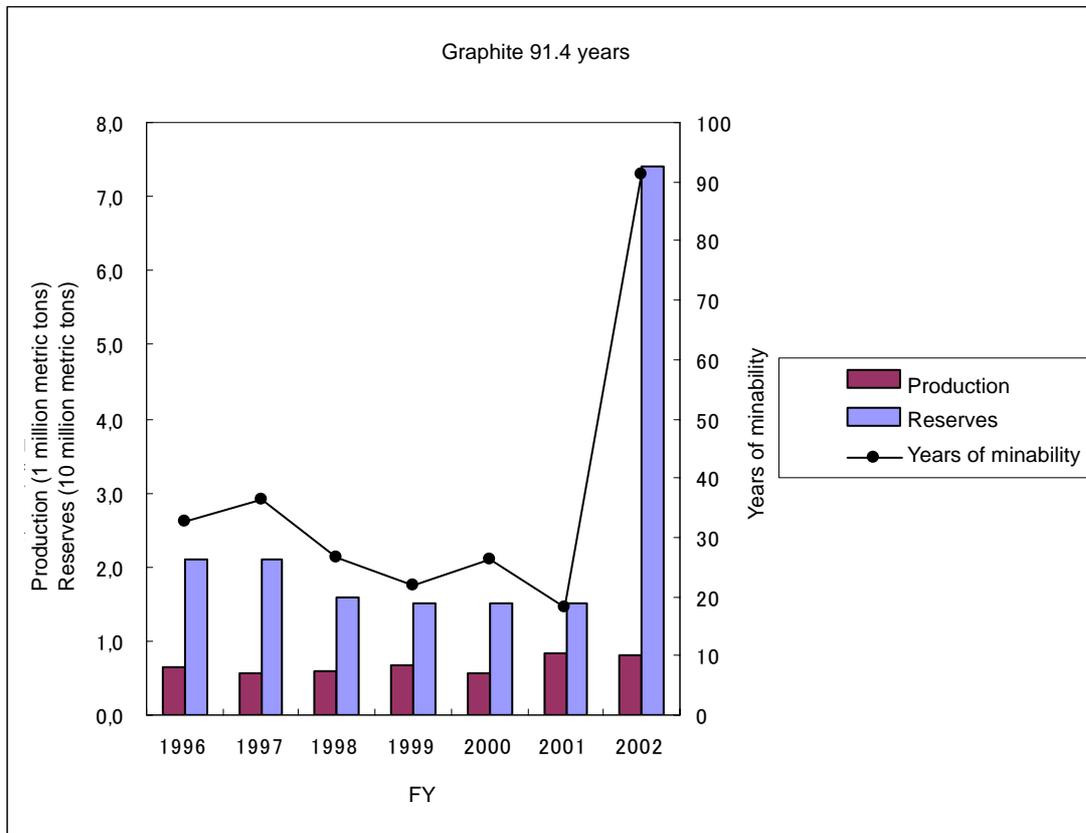
	Germanium			
	Production (kg)	Reserves	Reserve base	Resources
Year	Content			
1995	45,000			
1996	53,000			
1997	63,000			
1998	56,000			
1999	58,000			
2000	71,000			
2001	68,000			
2002	68,000			

Au Gold



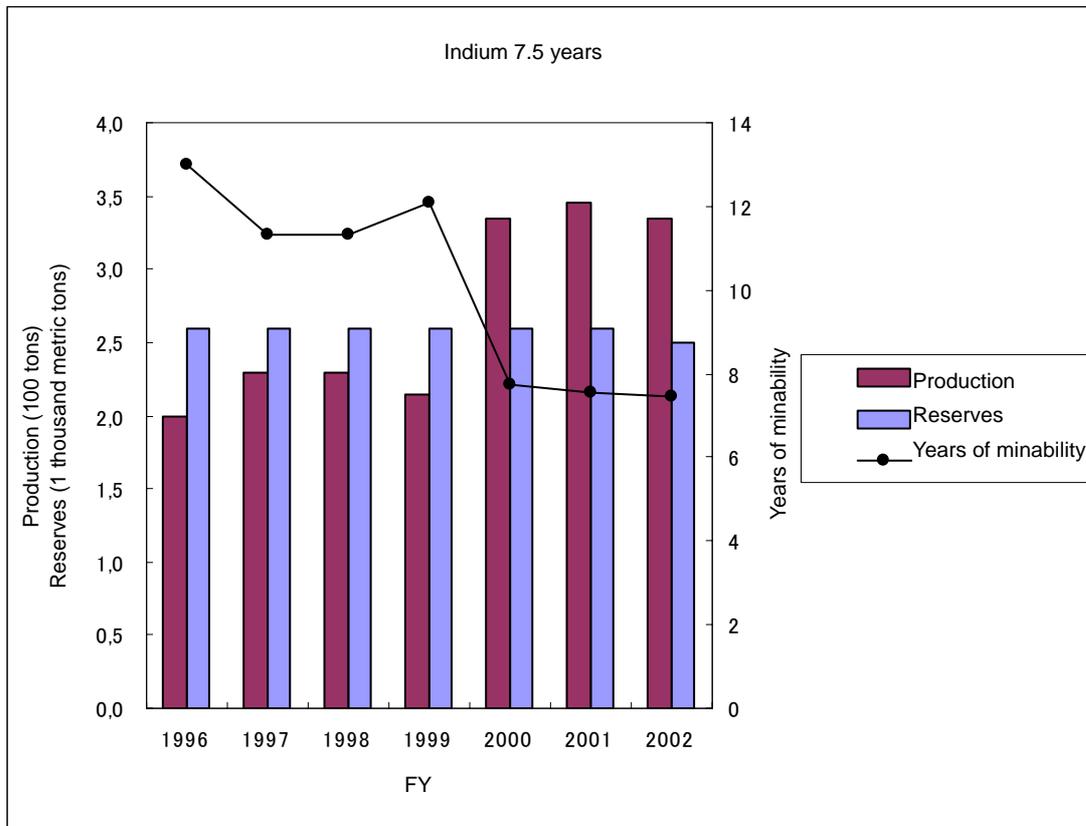
	Gold			
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year	Content			
1995	2,250			
1996	2,250	46,000	71,000	86,000
1997	2,410	45,000	72,000	89,000
1998	2,460	45,000	72,000	89,000
1999	2,540	49,000	77,000	100,000
2000	2,550	48,000	77,000	100,000
2001	2,570	50,000	78,000	100,000
2002	2,530	42,500	89,000	100,000

## Graphite (natural)



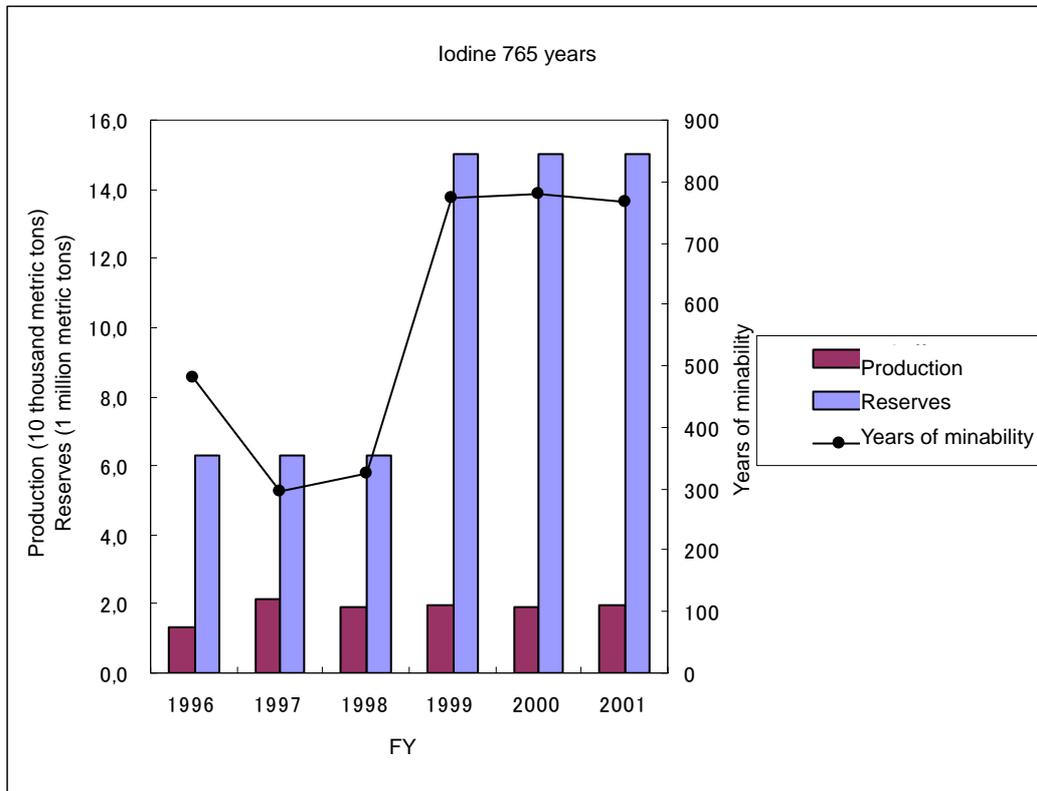
	Graphite (natural)			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year				
1995	720			
1996	644	21,000	380,000	800 million
1997	575	21,000	380,000	
1998	605	16,000	360,000	
1999	685	15,000	360,000	
2000	571	15,000	360,000	
2001	826	15,000	360,000	
2002	810	74,000	270,000	

In Indium



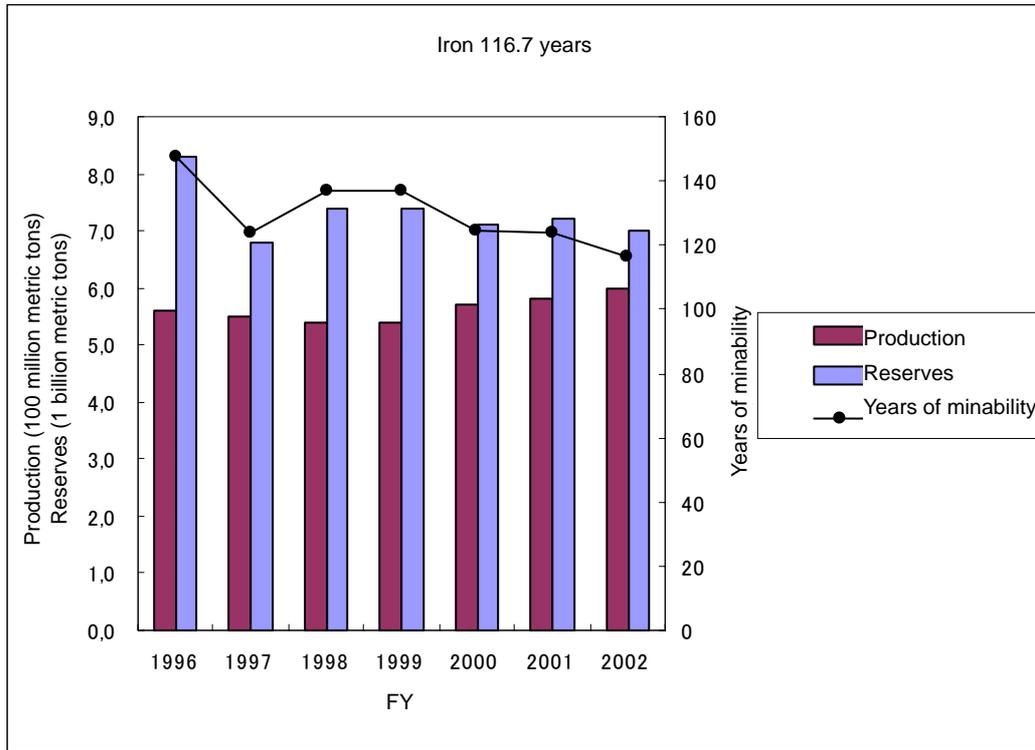
	Indium			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year				
1995	239			
1996	200	2,600	5,700	
1997	230	2,600	5,700	
1998	230	2,600	5,700	
1999	215	2,600	5,700	
2000	335	2,600	5,700	
2001	345	2,600	5,700	
2002	335	2,500	6,000	

## I Iodine



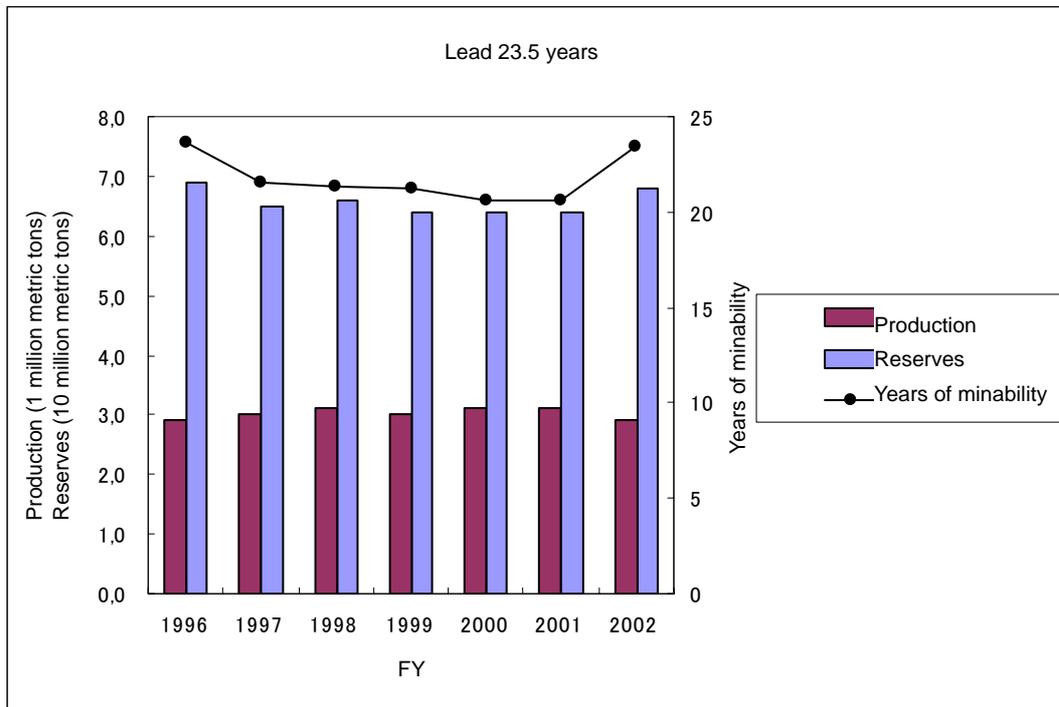
Iodine				
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year	Element			
1995	13,800			
1996	13,100	NA	NA	76 billion pounds
1997	13,100	6,300,000	NA	
1998	21,300	6,300,000	NA	
1999	19,300	6,300,000	NA	
2000	19,400	15,000,000	27,000,000	34 million tons
2001	19,200	15,000,000	27,000,000	
2002	19,600	15,000,000	27,000,000	

Fe Iron



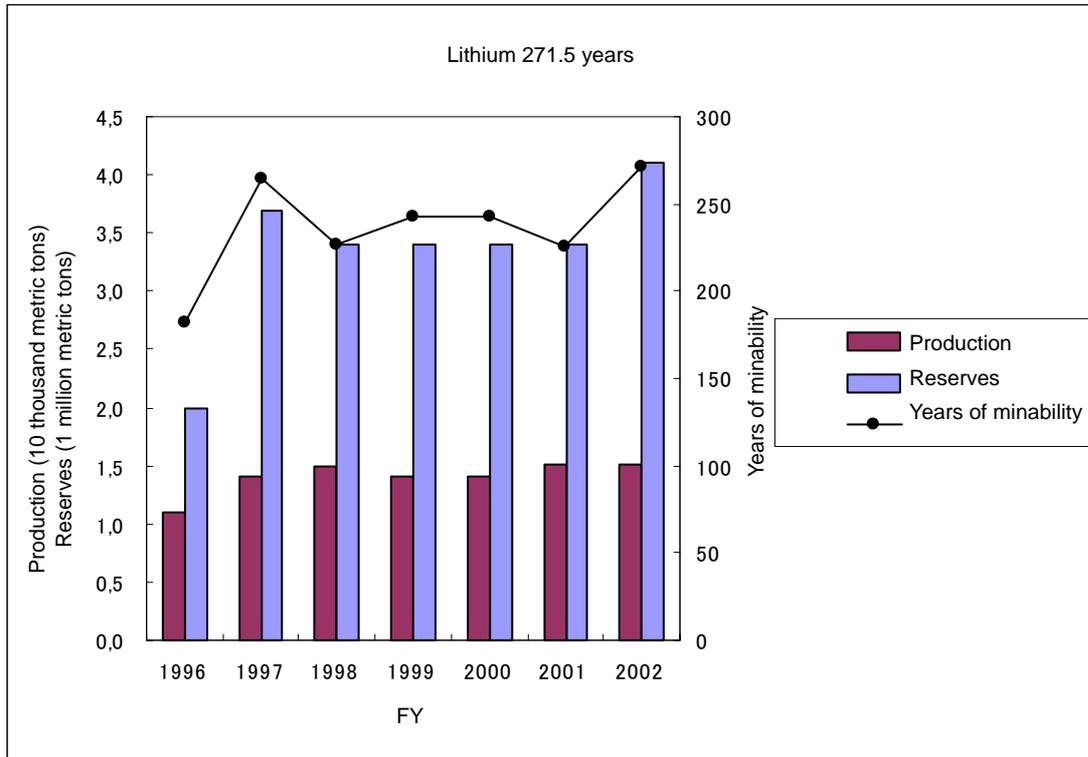
	Iron ore			
	Production (1000000t)	Reserves (1000000t)	Reserve base (1000000t)	Resources (t)
Year	Ore	Iron	Iron	
1995	1,000			
1996	1,020	83,000	124,000	230 billion
1997	1,040	68,000	112,000	
1998	1,020	74,000	160,000	
1999	994	74,000	160,000	
2000	1,060	71,000	160,000	
2001	1,060	72,000	160,000	
2002	1,100	70,000	160,000	

Pb Lead



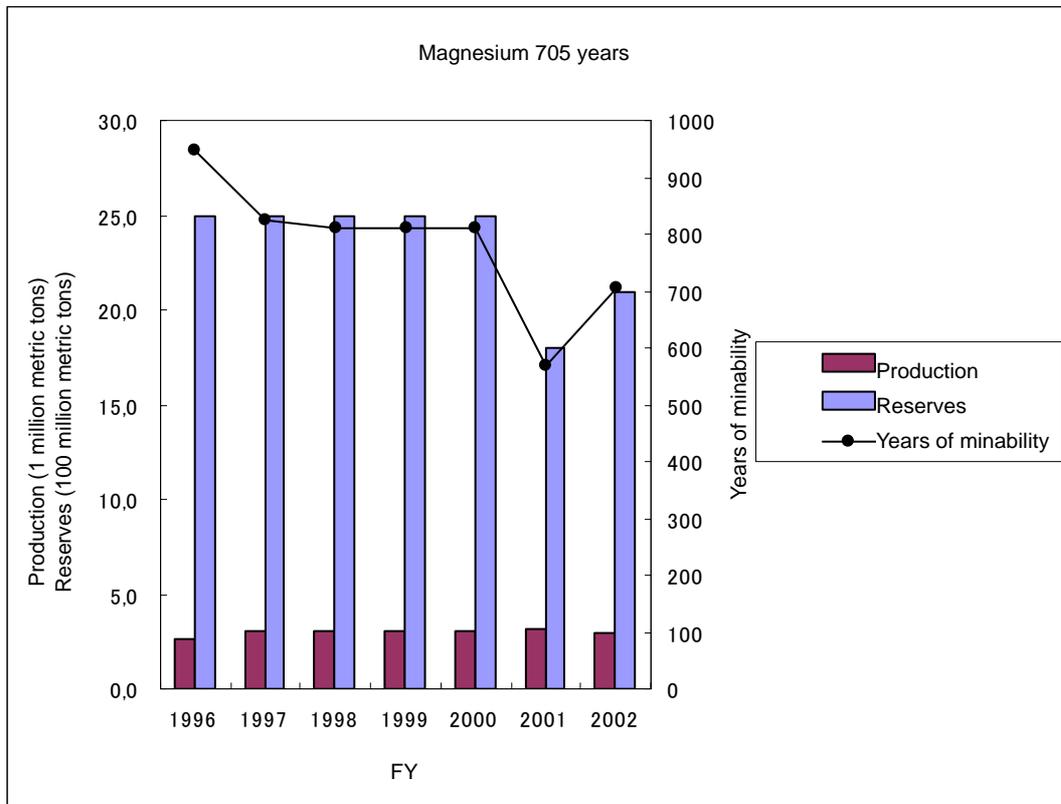
	Lead			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year	Content			
1995	2,710			
1996	2,920	69,000	120,000	>1.5 million
1997	3,010	65,000	120,000	
1998	3,100	66,000	140,000	
1999	3,020	64,000	143,000	
2000	3,100	64,000	130,000	
2001	3,100	64,000	130,000	
2002	2,900	68,000	140,000	

Li Lithium



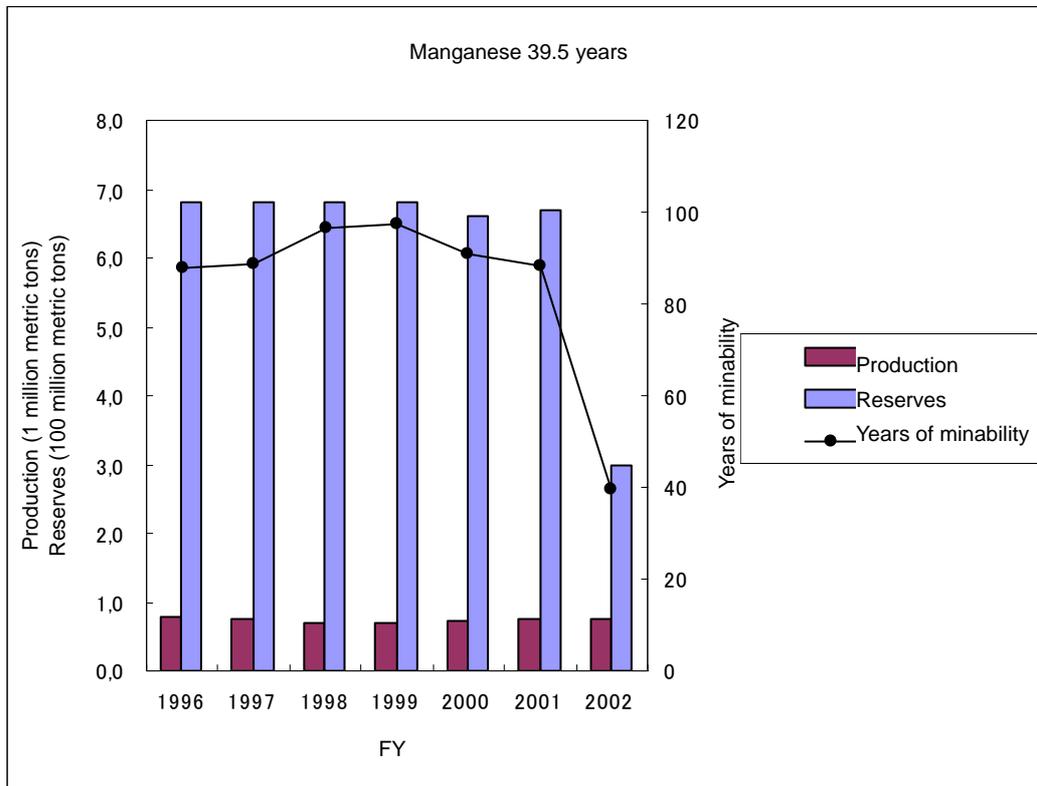
	Lithium			
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year	Contain			
1995	6,300			
1996	11,000	2,000,000	81,000,000	12 million
1997	14,000	3,700,000	9,400,000	
1998	15,000	3,400,000	9,400,000	
1999	14,000	3,400,000	9,400,000	
2000	14,000	3,400,000	9,400,000	
2001	15,100	3,400,000	9,400,000	
2002	15,100	4,100,000	11,000,000	>13 million

## Mg Magnesium



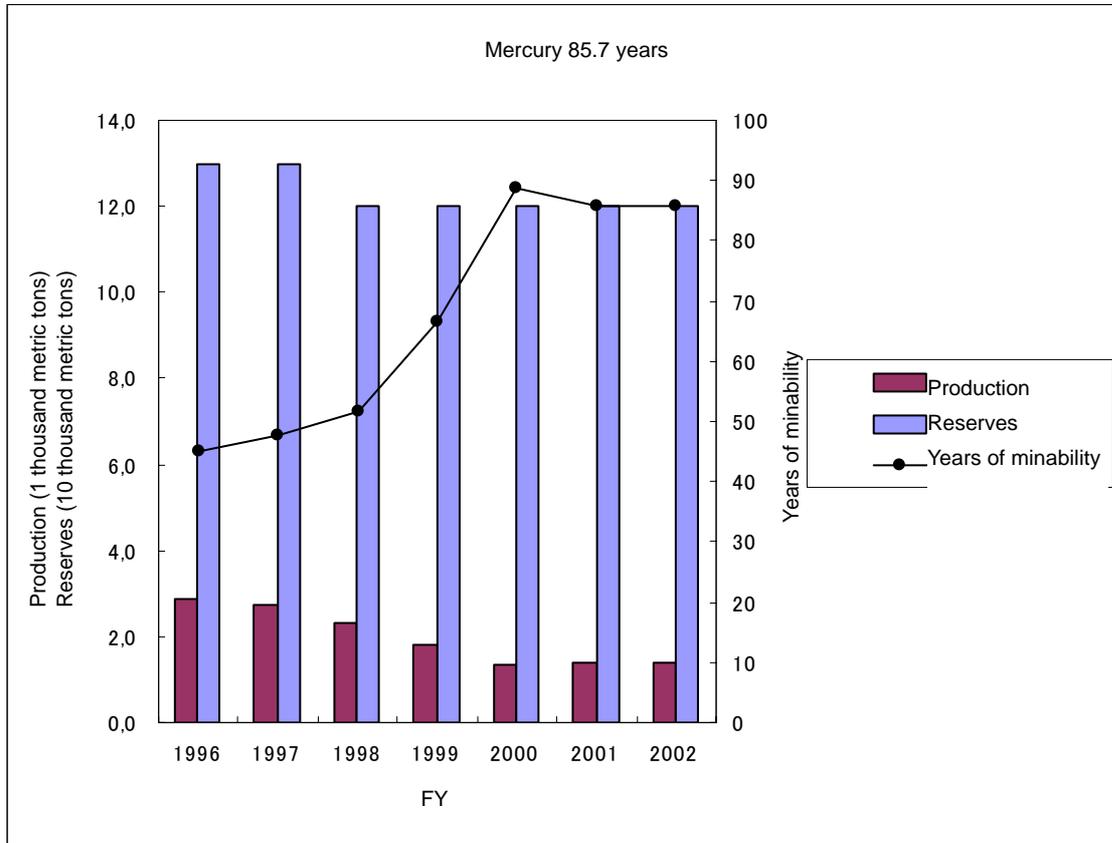
Year	Magnesium compound			Resources (t)
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	
1995	2,640			
1996	2,640	2,500,000	3,400,000	12 billion
1997	3,030	2,500,000	3,400,000	
1998	3,090	2,500,000	3,400,000	
1999	3,090	2,500,000	3,400,000	
2000	3,090	2,500,000	3,400,000	
2001	3,170	1,800,000	2,500,000	
2002	2,980	2,100,000	3,600,000	

Mn Manganese



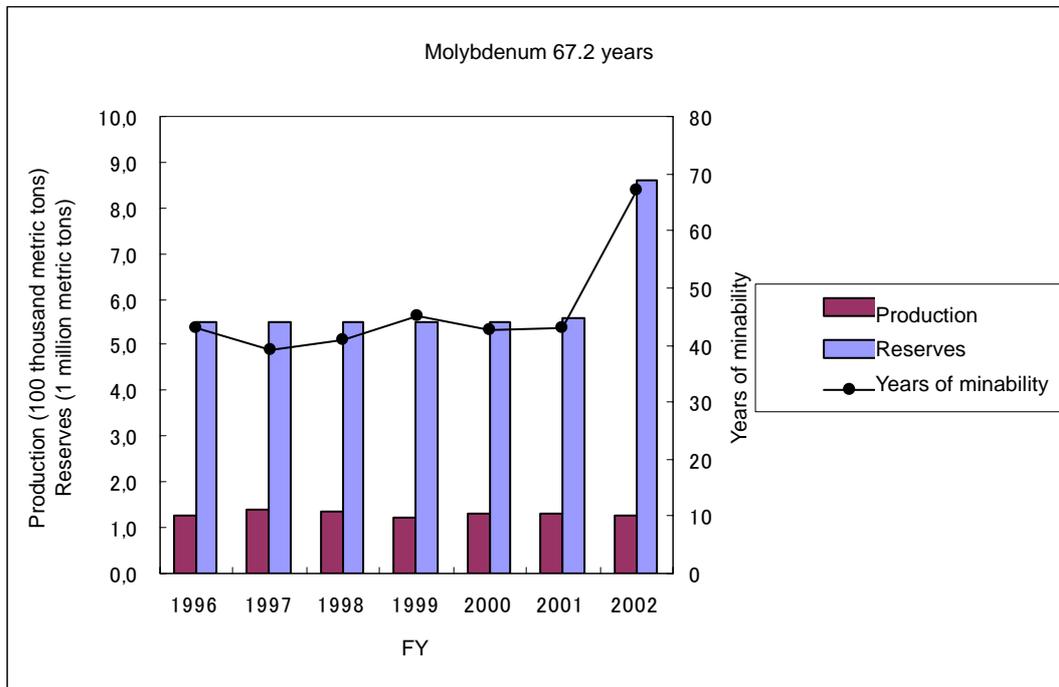
	Manganese			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources
Year	Gross			
1995	7,580			
1996	7,730	680,000	5,000,000	
1997	7,680	680,000	5,000,000	
1998	7,040	680,000	5,000,000	
1999	6,990	680,000	5,000,000	
2000	7,280	660,000	5,000,000	
2001	7,600	670,000	5,000,000	
2002	7,600	300,000	5,000,000	

## Hg Mercury



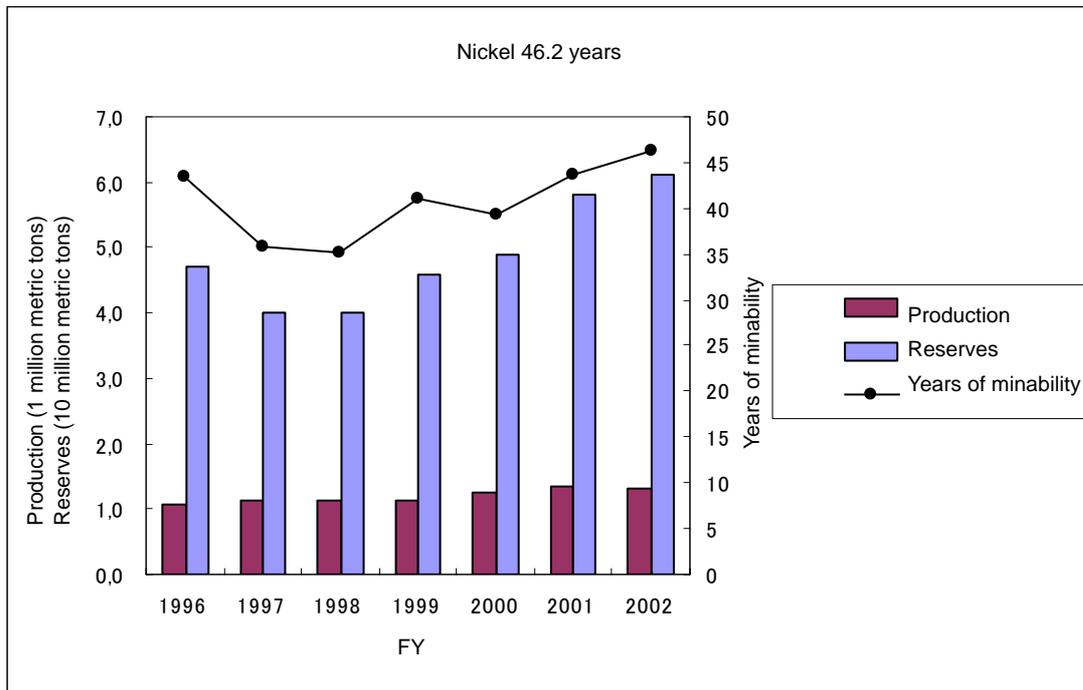
	Mercury			
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year	Content			
1995	2,820			
1996	2,890	130,000	240,000	600,000
1997	2,730	130,000	240,000	
1998	2,320	120,000	240,000	
1999	1,800	120,000	240,000	
2000	1,350	120,000	240,000	
2001	1,400	120,000	240,000	
2002	1,400	120,000	240,000	

Mo Molybdenum



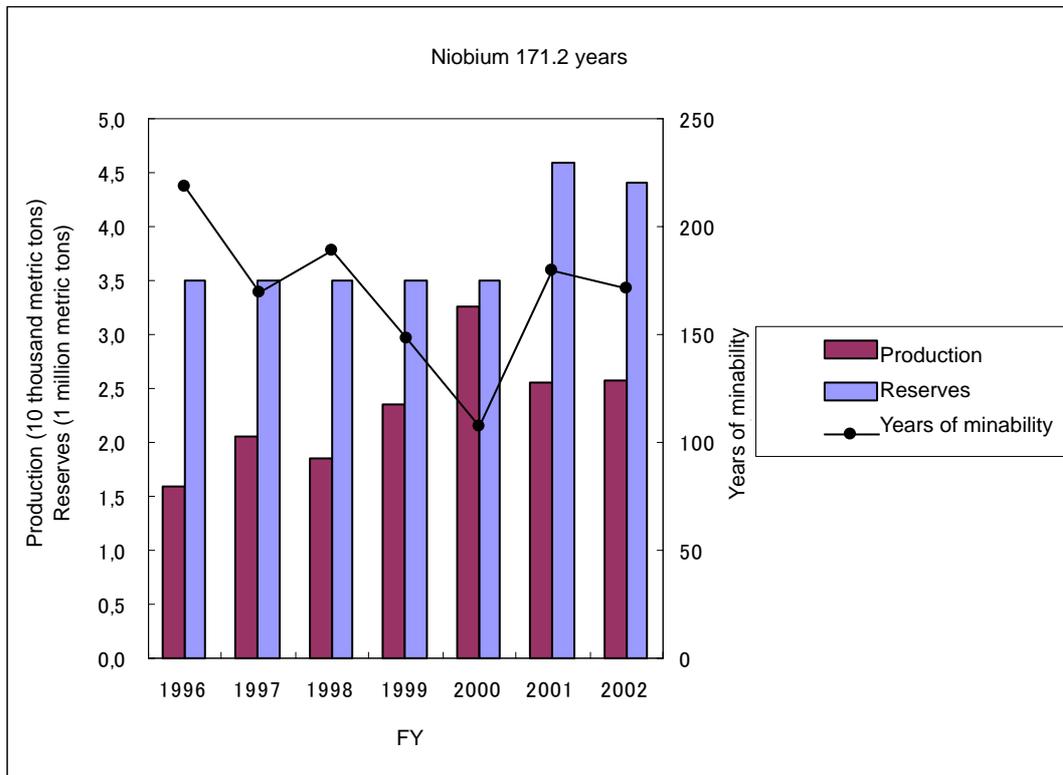
Molybdenum				
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year	Content			
1995	126,000			
1996	128,000	5,500,000	12,000,000	>17.4 million
1997	140,000	5,500,000	1,200,000	
1998	135,000	5,500,000	1,200,000	
1999	122,000	5,500,000	1,200,000	>17.5 million
2000	129,000	5,500,000	1,200,000	
2001	130,000	5,600,000	11,000,000	
2002	128,000	8,600,000	19,000,000	>18.4 million

Ni Nickel



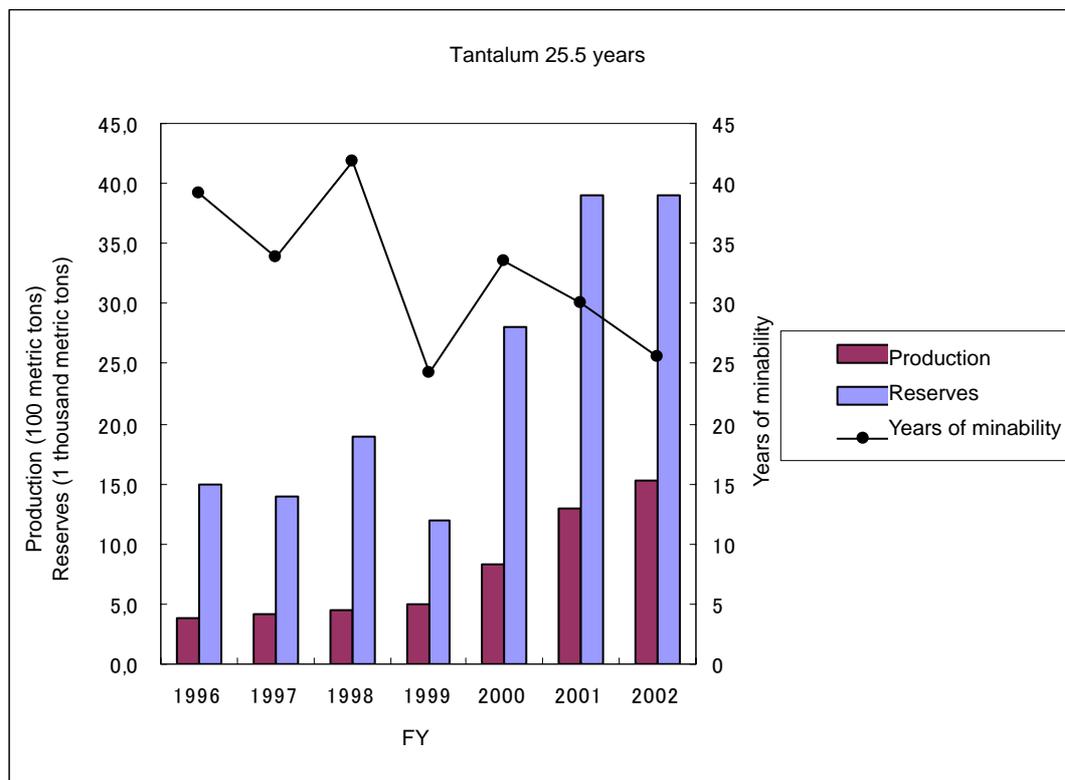
	Nickel			
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year	Content			
1995	1,040,000			
1996	1,080,000	47,000,000	110,000,000	130 million
1997	1,120,000	40,000,000	140,000,000	
1998	1,140,000	40,000,000	140,000,000	
1999	1,120,000	46,000,000	140,000,000	
2000	1,250,000	49,000,000	150,000,000	
2001	1,330,000	58,000,000	160,000,000	
2002	1,320,000	61,000,000	140,000,000	

Nb Niobium



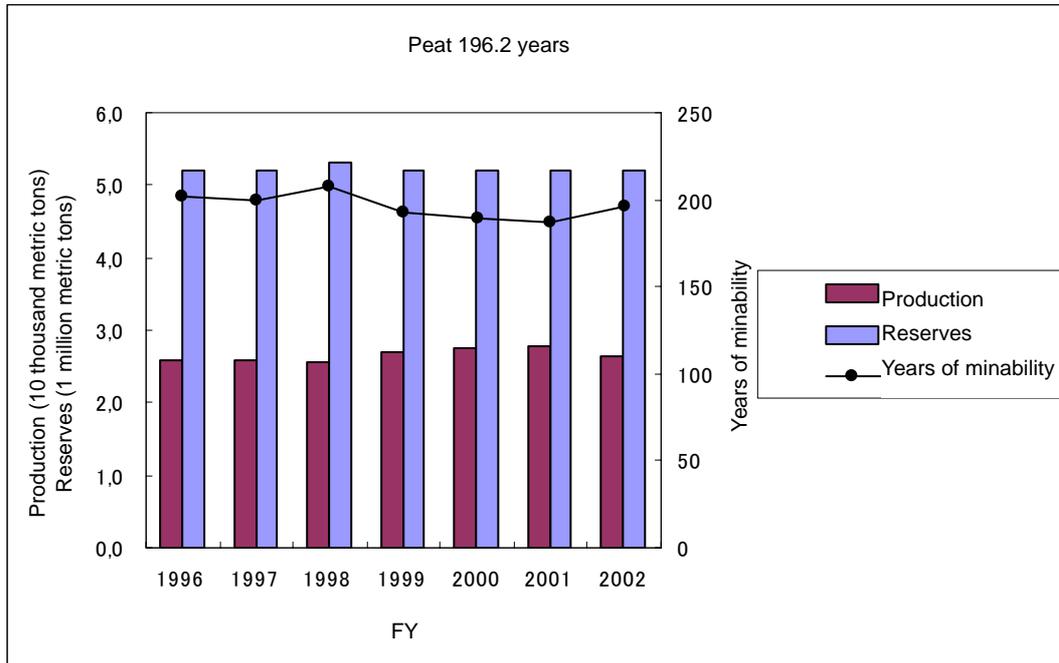
	Niobium			
	Production (1000 kg)	Reserves (1000 kg)	Reserve base (1000 kg)	Resources
Year	Content			
1995	17,800			
1996	16,000	3,500,000	4,200,000	360 million kg
1997	20,600	3,500,000	4,200,000	360,000 t
1998	18,500	3,500,000	5,600,000	
1999	23,600	3,500,000	5,500,000	
2000	32,600	3,500,000	5,500,000	
2001	25,600	4,600,000	5,700,000	
2002	25,700	4,400,000	5,200,000	

Ta Tantalum



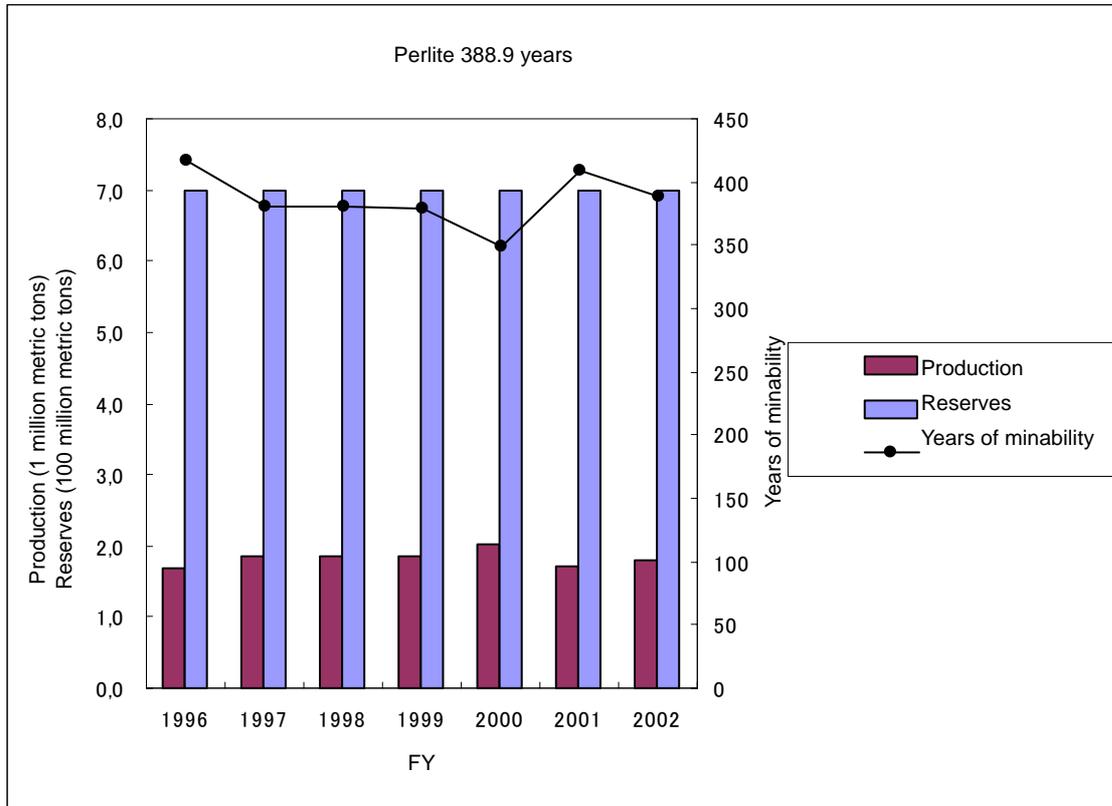
	Tantalum			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year	Content			
1995	356			
1996	383	15,000	26,000	
1997	413	14,000	24,000	
1998	454	19,000	24,000	
1999	495	12,000	36,000	
2000	836	28,000	60,000	
2001	1,300	39,000	120,000	
2002	1,530	39,000	110,000	

## Peat



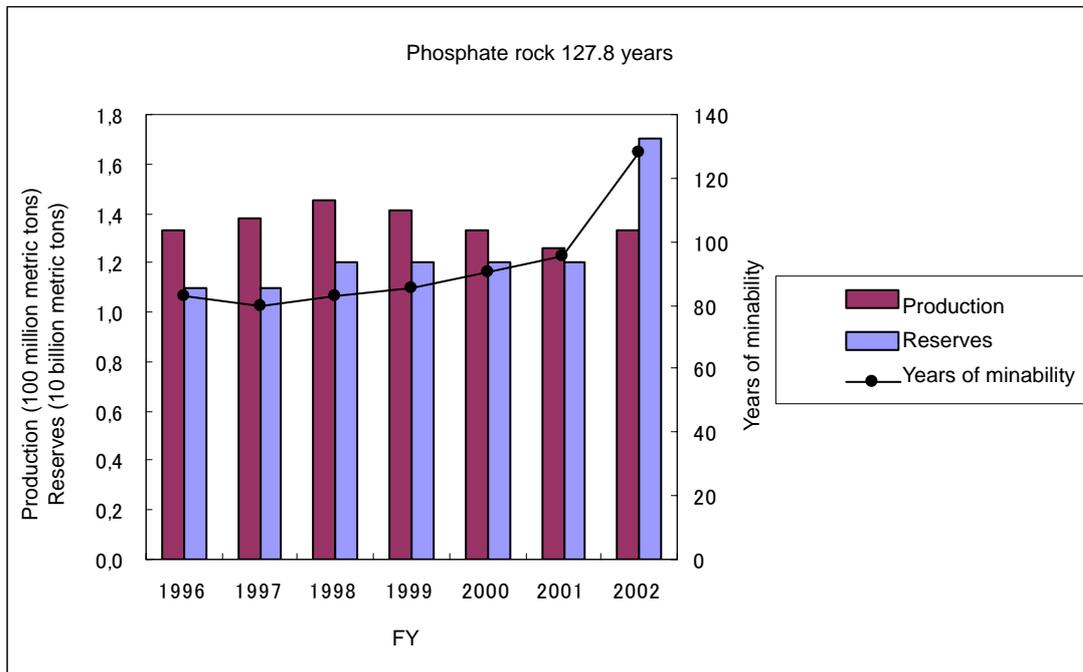
	Peat			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year				
1995	128,000			
1996	25,800	5,200,000	460,000,000	1.9 trillion
1997	26,000	5,200,000	460,000,000	
1998	25,500	5,300,000	460,000,000	
1999	27,000	5,200,000	200,000,000	
2000	27,400	5,200,000	200,000,000	2 trillion
2001	27,900	5,200,000	200,000,000	
2002	26,500	5,200,000	200,000,000	

## Perlite



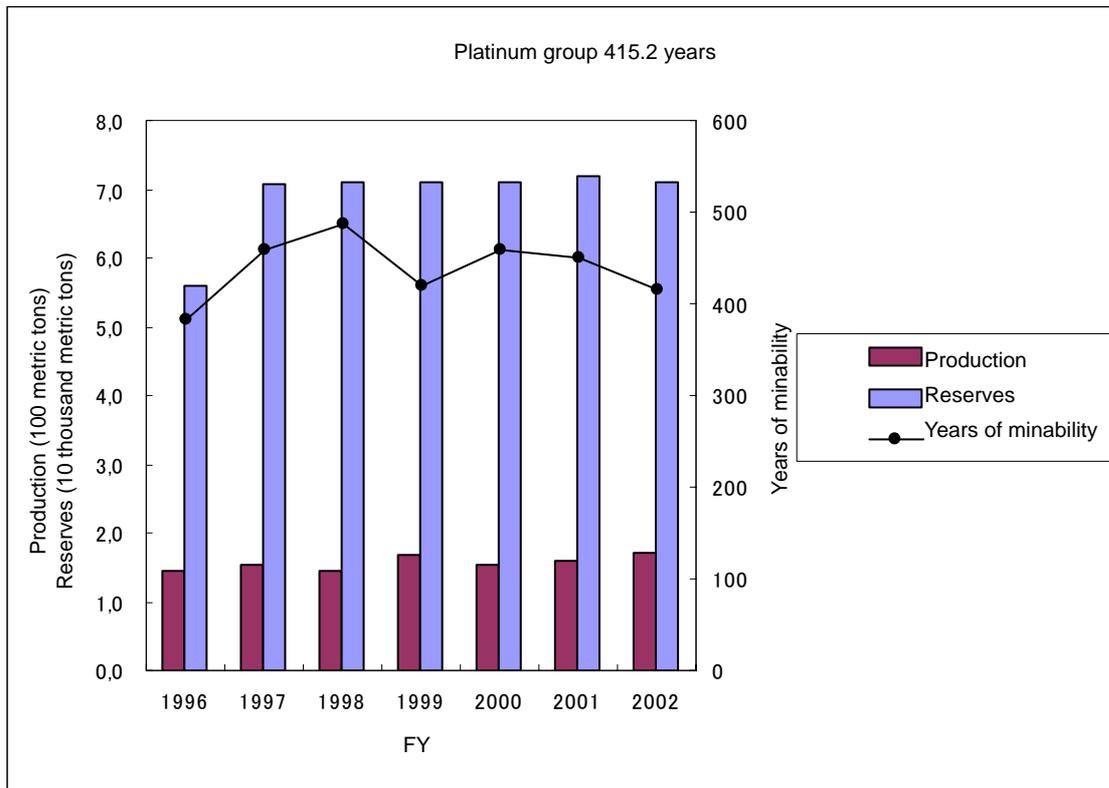
	Perlite			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources
Year				
1995	1,480			
1996	1,682	700,000	2,000,000	Little information
1997	1,840	700,000	2,000,000	
1998	1,840	700,000	2,000,000	
1999	1,850	700,000	2,000,000	
2000	2,010	700,000	2,000,000	
2001	1,710	700,000	2,000,000	
2002	1,800	700,000	7,700,000	

## Phosphate rock



Phosphate rock				
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources
Year				
1995	131,000			
1996	133,000	11,000,000	34,000,000	
1997	138,000	11,000,000	33,000,000	
1998	145,000	12,000,000	35,000,000	
1999	141,000	12,000,000	36,000,000	
2000	133,000	12,000,000	37,000,000	
2001	126,000	12,000,000	47,000,000	
2002	133,000	17,000,000	50,000,000	

Platinum group (Ru, Rh, Pd, Os, Ir, Pt)

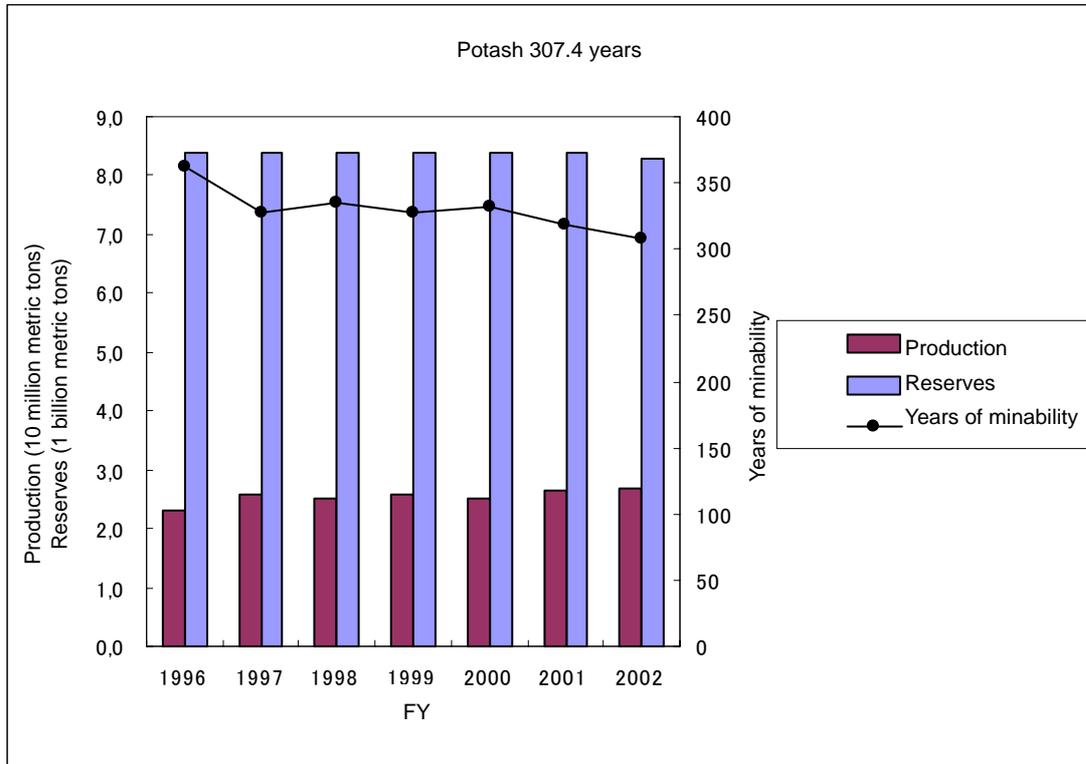


Platinum group				
	Production (kg)	Reserves (kg)	Reserve base (kg)	Resources (kg)
Year				
1995	145,000			
1996	146,000	56,000,000	66,000,000	100 million
1997	154,000	70,600,000	77,500,000	
1998	146,000	71,000,000	78,000,000	
1999	169,000	71,000,000	78,000,000	
2000	155,000	71,000,000	79,000,000	
2001	160,000	72,000,000	73,000,000	
2002	171,000	71,000,000	80,000,000	

Pd Palladium

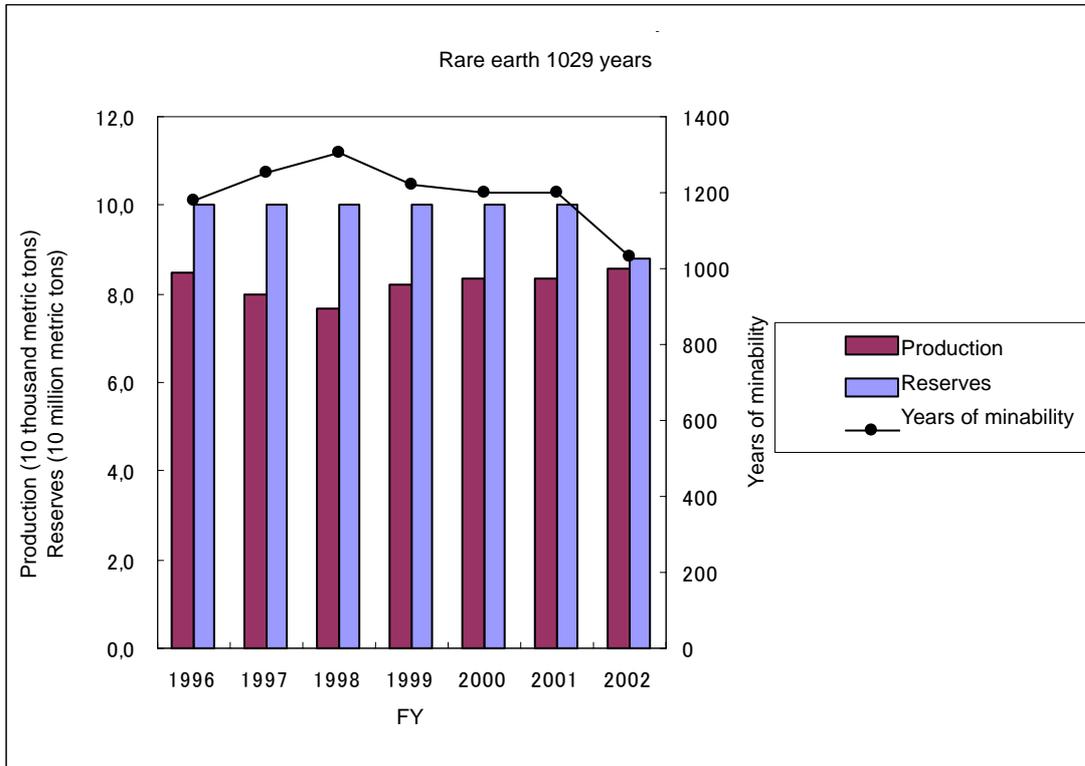
	Palladium			
	Production (kg)	Reserves	Reserve base	Resources
Year				
1995	112,000			
1996	111,000			
1997	119,000			
1998	150,000			
1999	178,000			
2000	174,000			
2001	179,000			
2002	193,000			

## Potash



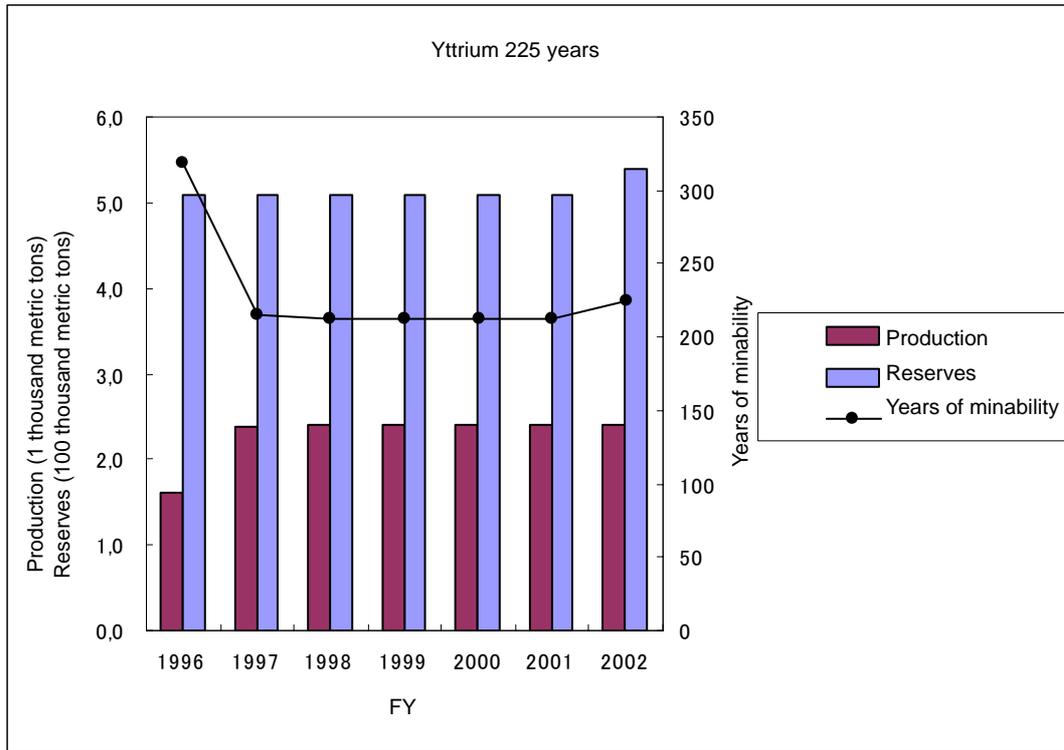
	Potash			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources
Year	K <sub>2</sub> O			
1995	24,300			
1996	23,200	8,400,000	17,000,000	
1997	25,700	8,400,000	17,000,000	
1998	25,100	8,400,000	17,000,000	
1999	25,700	8,400,000	17,000,000	
2000	25,300	8,400,000	17,000,000	
2001	26,400	8,400,000	17,000,000	
2002	27,000	8,300,000	17,000,000	

Rare earth



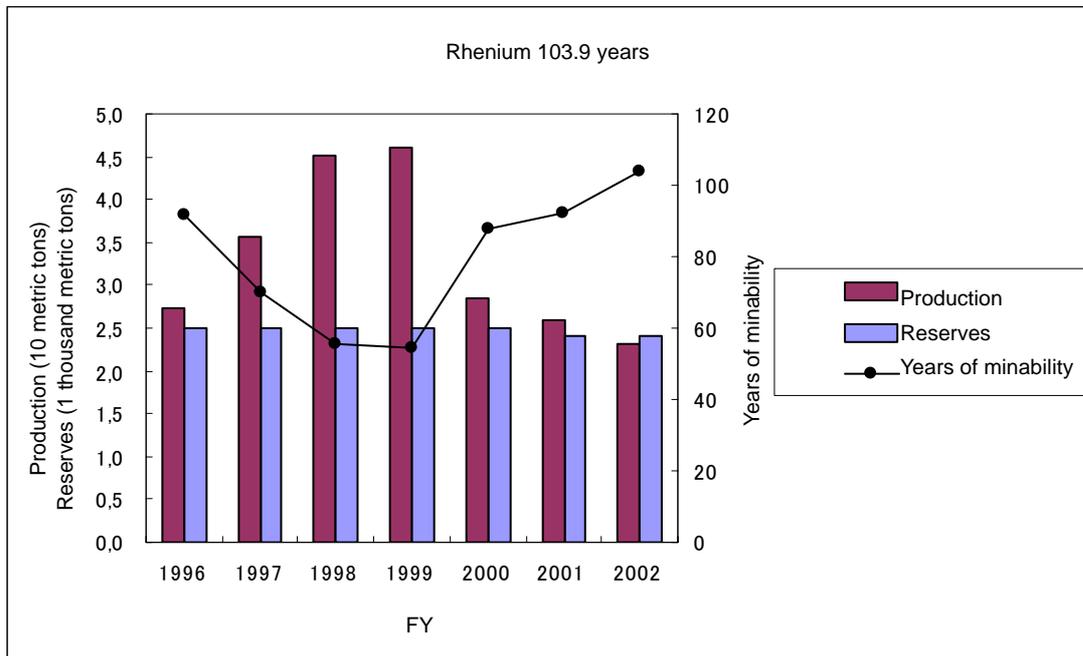
	Rare earth			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year	Content			
1995	79,900			
1996	84,800	100,000,000	110,000,000	
1997	79,700	100,000,000	110,000,000	
1998	76,600	100,000,000	110,000,000	
1999	82,000	100,000,000	110,000,000	
2000	83,500	100,000,000	110,000,000	
2001	83,500	100,000,000	110,000,000	
2002	85,500	88,000,000	150,000,000	

## Y Yttrium



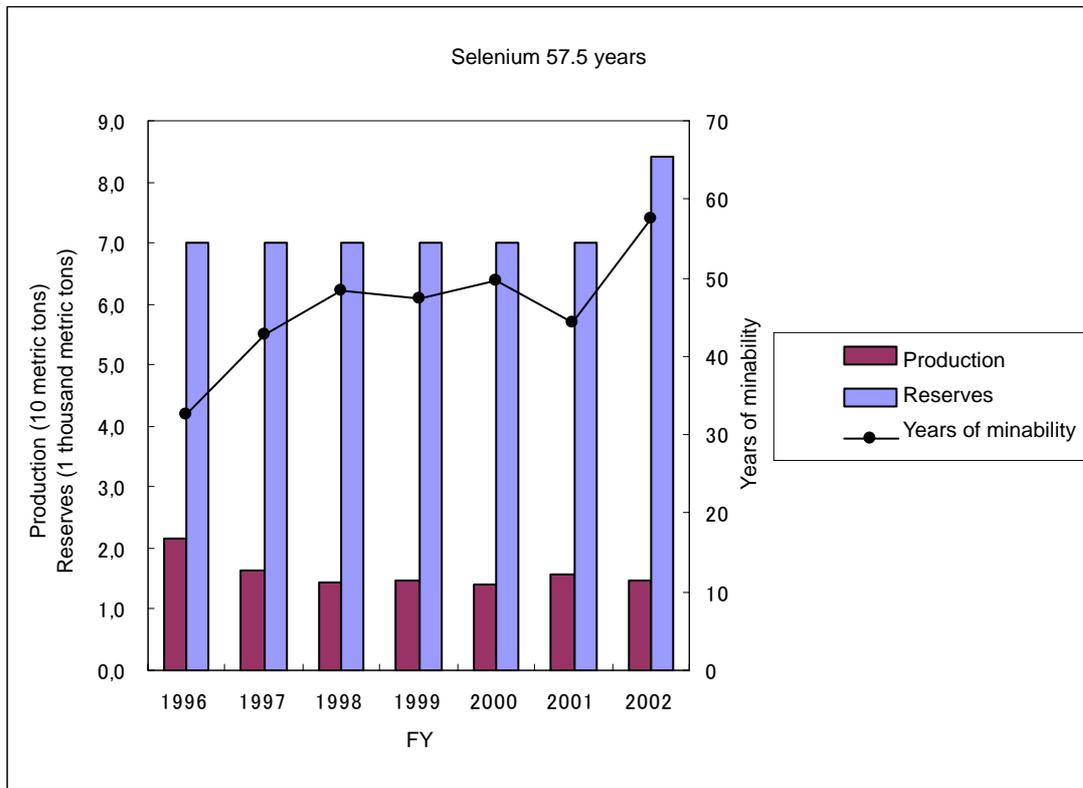
	Yttrium			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year	Y <sub>2</sub> O <sub>3</sub>			
1995	1,450			
1996	1,600	510,000	560,000	
1997	2,370	510,000	560,000	
1998	2,400	510,000	560,000	
1999	2,400	510,000	560,000	
2000	2,400	510,000	560,000	
2001	2,400	510,000	560,000	
2002	2,400	540,000	610,000	

Re Rhenium



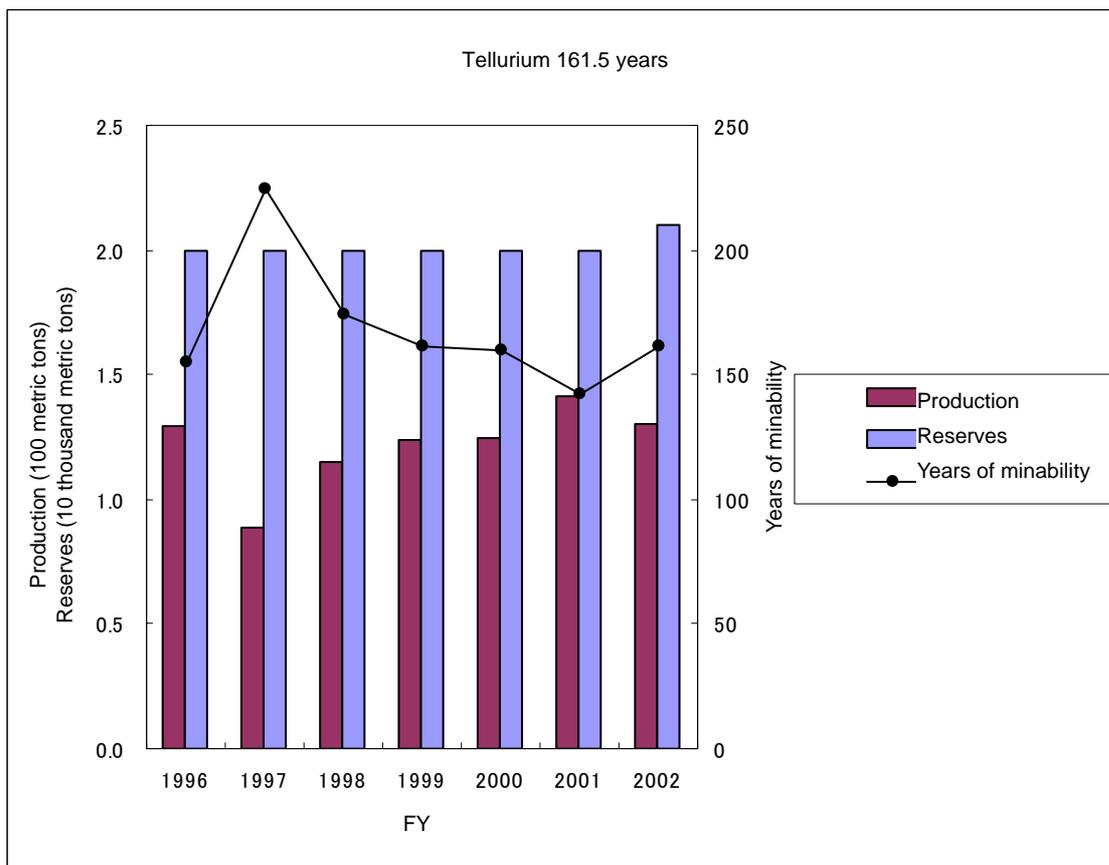
	Rhenium			
	Production (kg)	Reserves (kg)	Reserve base (kg)	Resources (kg)
Year	Content			
1995	28,200			
1996	27,200	2,500,000	11,000,000	11 million
1997	35,600	2,500,000	11,000,000	
1998	45,100	2,500,000	11,000,000	
1999	46,000	2,500,000	11,000,000	
2000	28,400	2,500,000	11,000,000	
2001	26,000	2,400,000	10,000,000	
2002	23,100	2,400,000	10,000,000	

Se Selenium



	Selenium			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year	Content			
1995	2,070			
1996	2,150	70,000	130,000	
1997	1,640	70,000	130,000	
1998	1,450	70,000	130,000	
1999	1,480	70,000	130,000	
2000	1,410	70,000	130,000	
2001	1,580	70,000	130,000	
2002	1,460	84,000	180,000	

Te Tellurium

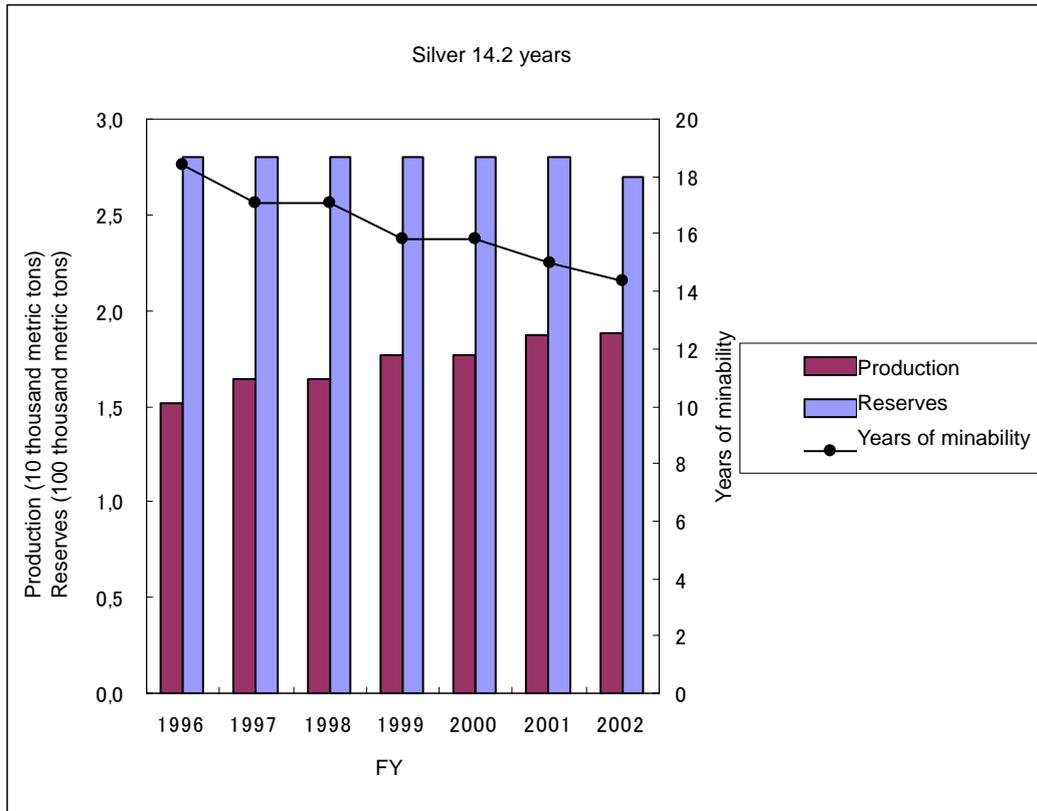


	Tellurium			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year	Content			
1995	NA			
1996	129	20,000	38,000	
1997	89	20,000	38,000	
1998	115	20,000	38,000	
1999	124	20,000	38,000	
2000	125	20,000	38,000	
2001	141	20,000	38,000	
2002	130	21,000	47,000	

Si Silicon

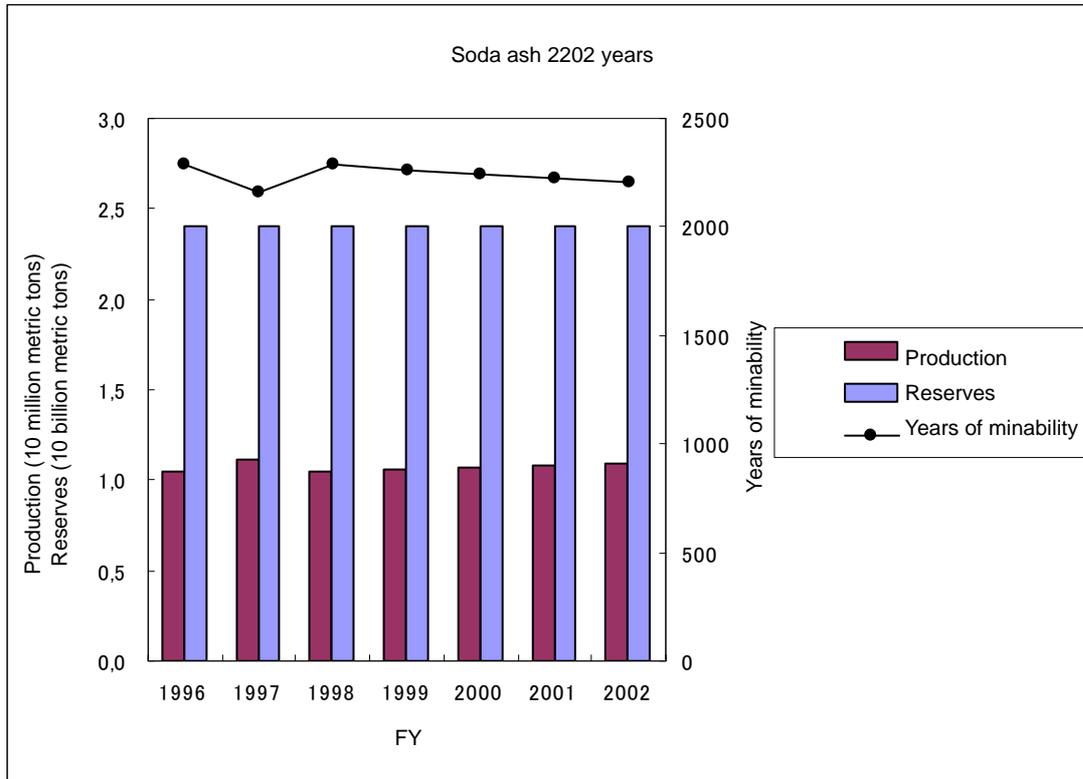
	Silicon			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources
Year	Content			
1995	3,100			
1996	3,200			
1997	3,400			
1998	3,200			
1999	3,400			
2000	3,500			
2001	3,500			
2002	4,100			

Ag Silver



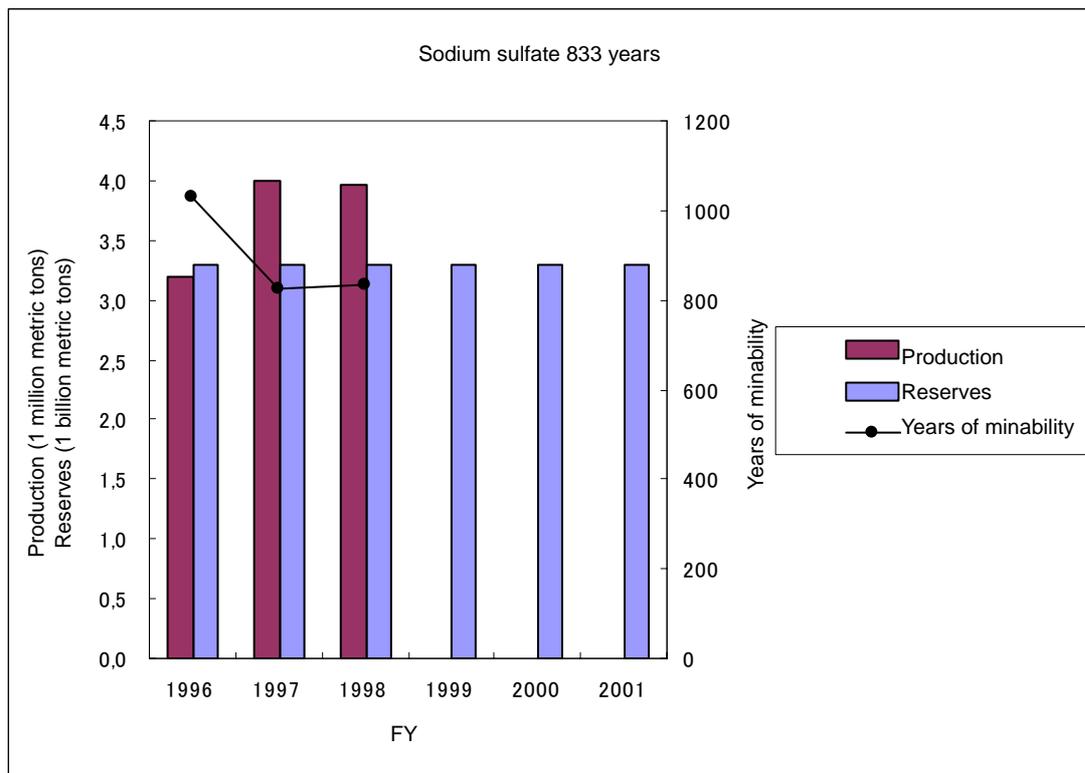
	Silver			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year	Content			
1995	14,600			
1996	15,200	280,000	420,000	
1997	16,400	280,000	420,000	
1998	16,400	280,000	420,000	
1999	17,700	280,000	420,000	
2000	17,700	280,000	420,000	
2001	18,700	280,000	430,000	
2002	18,800	270,000	520,000	

## Soda ash



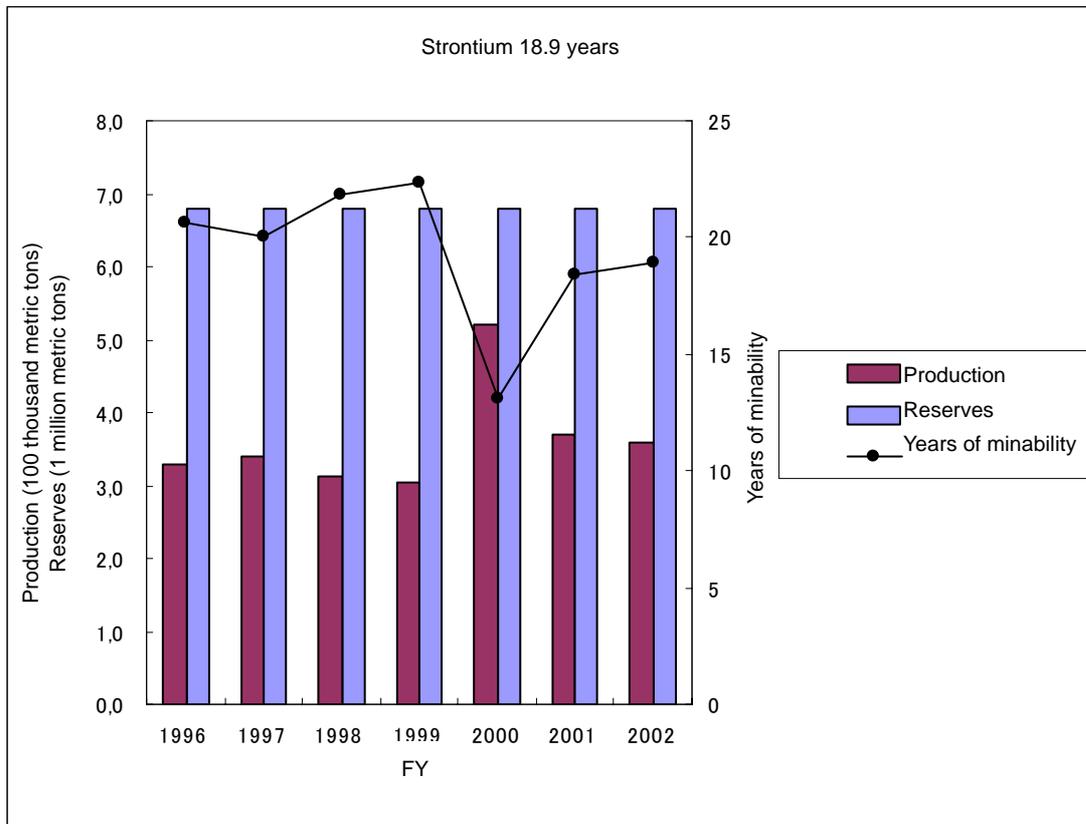
	Soda ash			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources
Year				
1995	10,400			
1996	10,500	24,000,000	40,000,000	
1997	11,100	24,000,000	40,000,000	
1998	10,500	24,000,000	40,000,000	
1999	10,600	24,000,000	40,000,000	
2000	10,700	24,000,000	40,000,000	
2001	10,800	24,000,000	40,000,000	
2002	10,900	24,000,000	40,000,000	

## Sodium sulfate



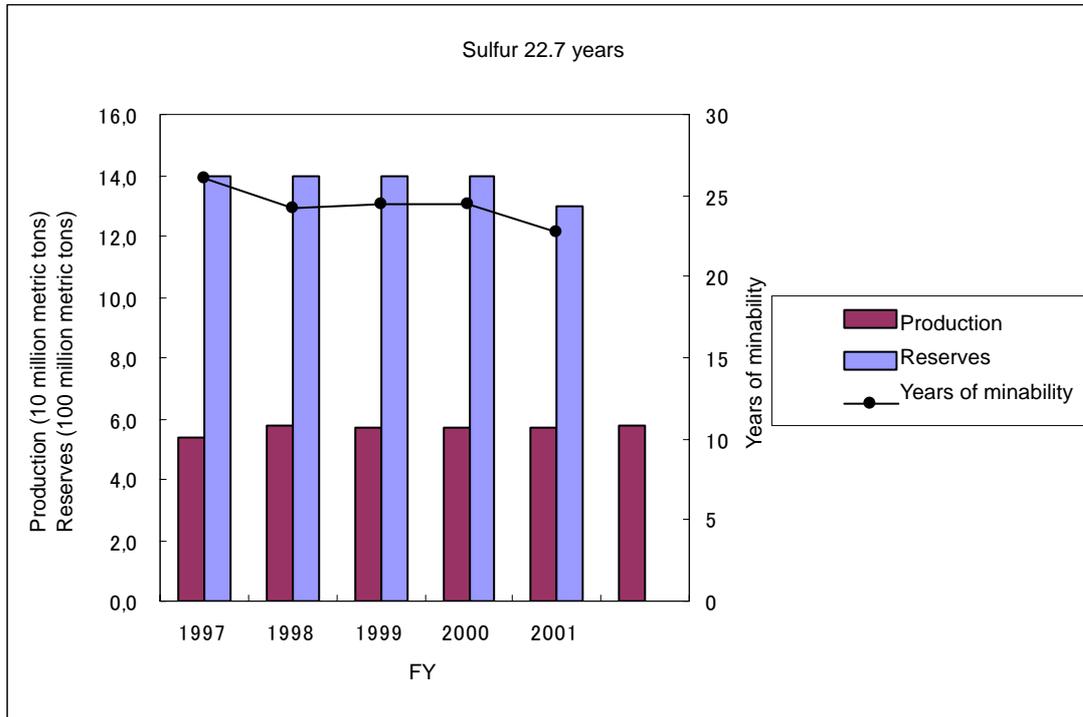
Sodium sulfate				
a	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources
Year				
1995	2,500			
1996	3,200	3,300,000	4,600,000	
1997	3,990	3,300,000	4,600,000	
1998	3,960	3,300,000	4,600,000	
1999		3,300,000	4,600,000	
2000		3,300,000	4,600,000	
2001		3,300,000	4,600,000	
2002				

Sr Strontium



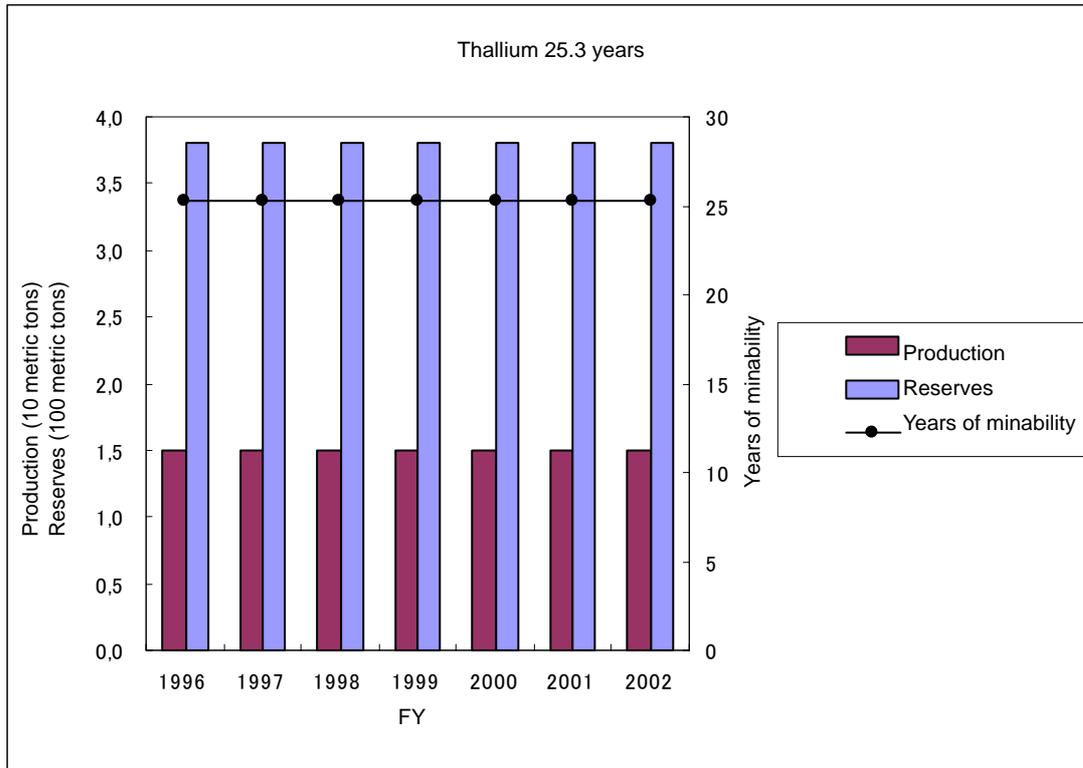
	Strontium			
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year	Content			
1995	170,000			
1996	330,000	6,800,000	12,000,000	1 billion
1997	340,000	6,800,000	12,000,000	
1998	311,000	6,800,000	12,000,000	
1999	304,000	6,800,000	12,000,000	
2000	520,000	6,800,000	12,000,000	
2001	370,000	6,800,000	12,000,000	
2002	360,000	6,800,000	12,000,000	

## S Sulfur



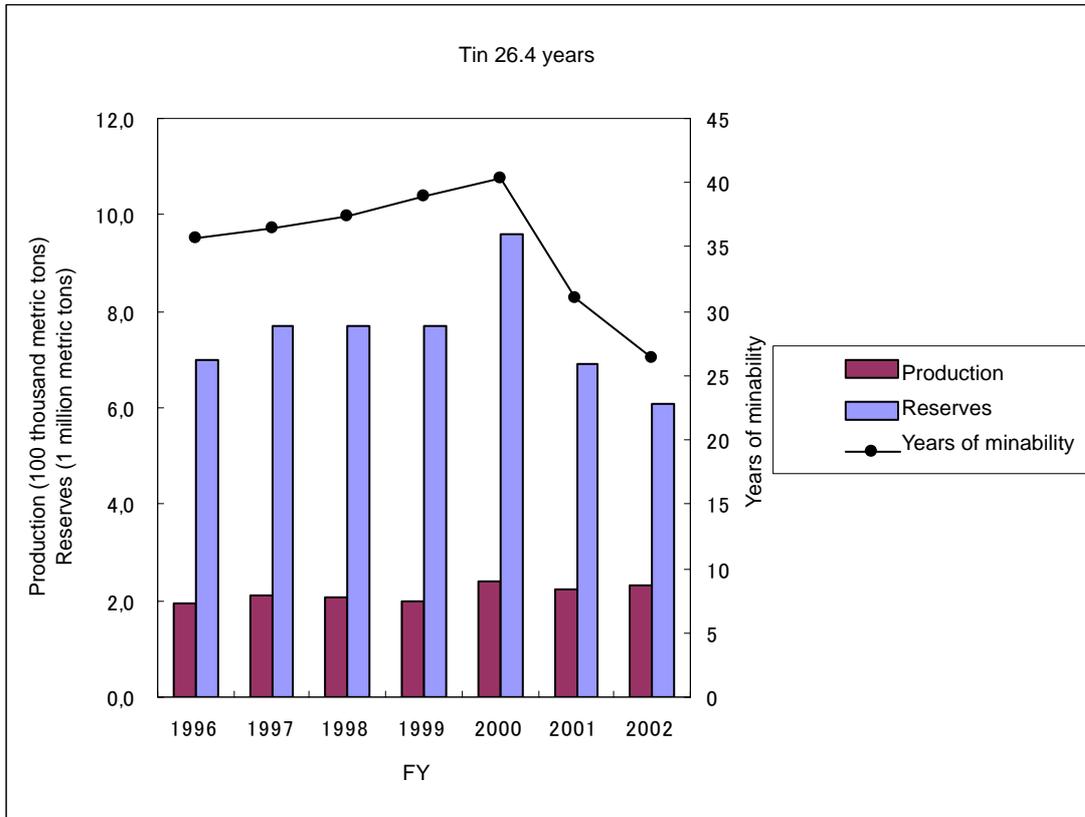
Sulfur				
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year				
1995	54,300			
1996	52,400			60 billion
1997	53,600	1,400,000	3,500,000	
1998	57,800	1,400,000	3,500,000	
1999	57,100	1,400,000	3,500,000	
2000	57,200	1,400,000	3,500,000	
2001	57,300	1,300,000	3,500,000	
2002	58,000			

## TI Thallium



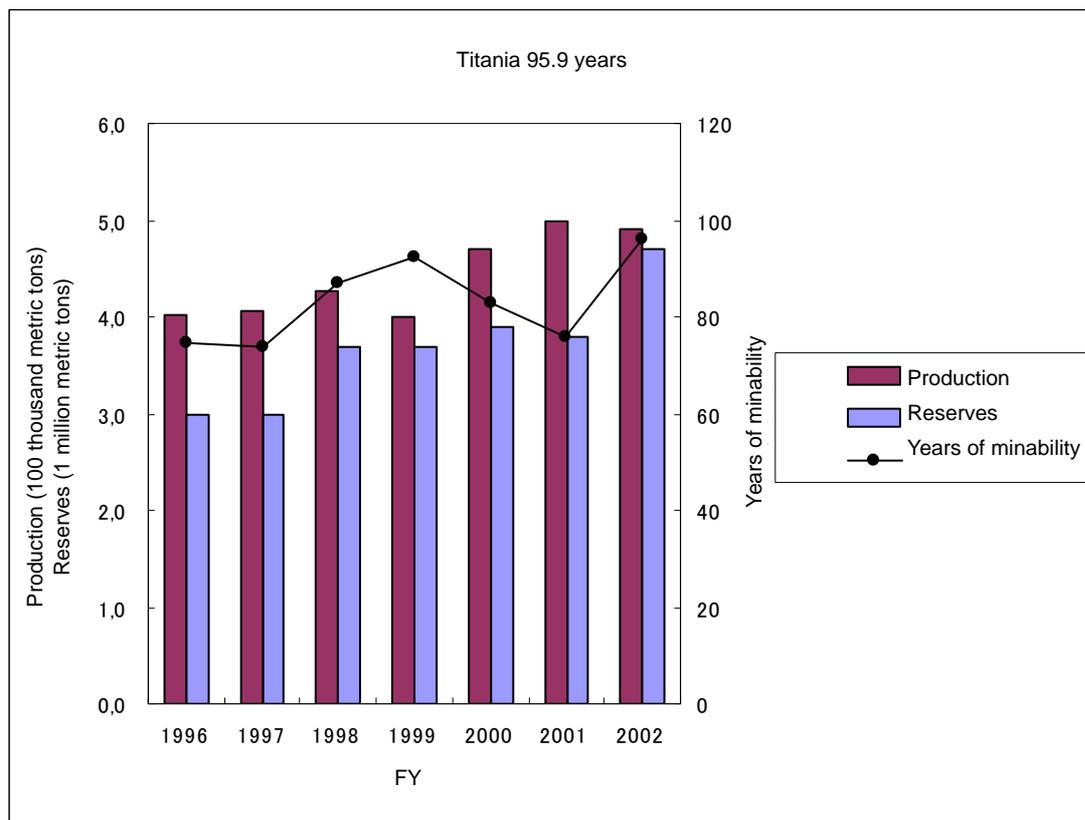
	Thallium			
	Production (kg)	Reserves (kg)	Reserve base (kg)	Resources (kg)
Year				
1995	15,000			
1996	15,000	380,000	650,000	17 million
1997	15,000	380,000	650,000	
1998	15,000	380,000	650,000	
1999	15,000	380,000	650,000	
2000	15,000	380,000	650,000	
2001	15,000	380,000	650,000	
2002	15,000	380,000	650,000	

Sn Tin



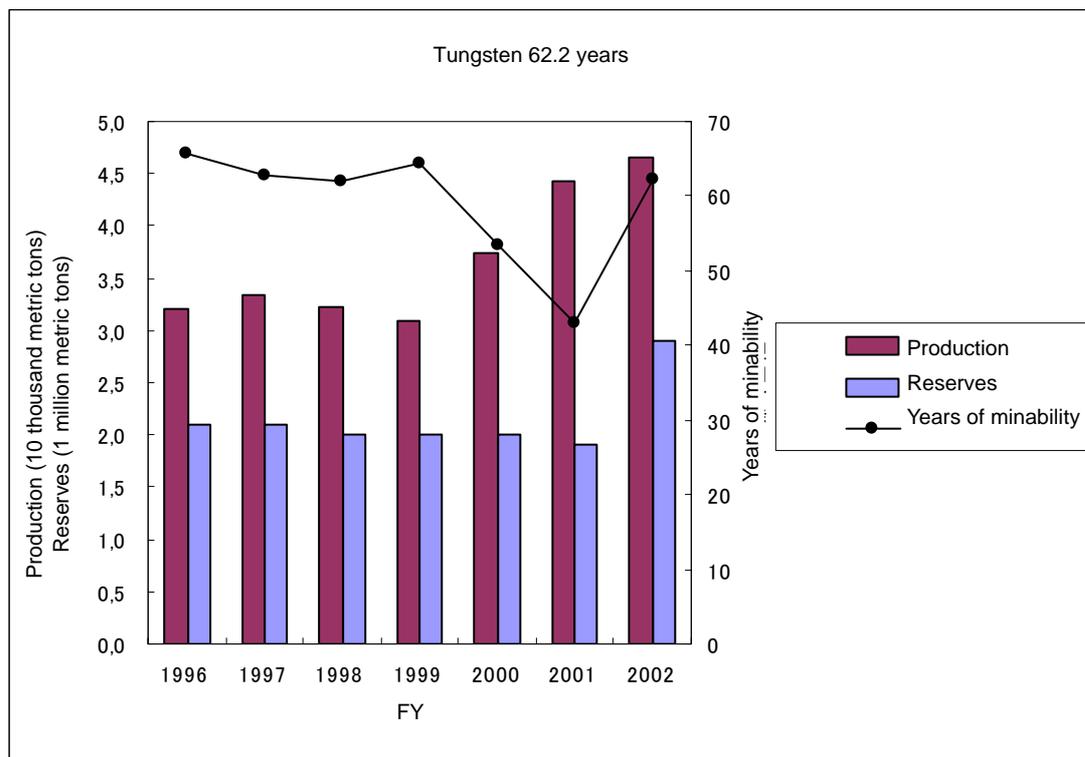
	Tin			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year	Content			
1995	189,000			
1996	196,000	7,000,000	10,000,000	
1997	211,000	7,700,000	12,000,000	
1998	206,000	7,700,000	12,000,000	
1999	198,000	7,700,000	12,000,000	
2000	238,000	9,600,000	12,000,000	
2001	222,000	6,900,000	12,000,000	
2002	231,000	6,100,000	11,000,000	

## Ti Titanium



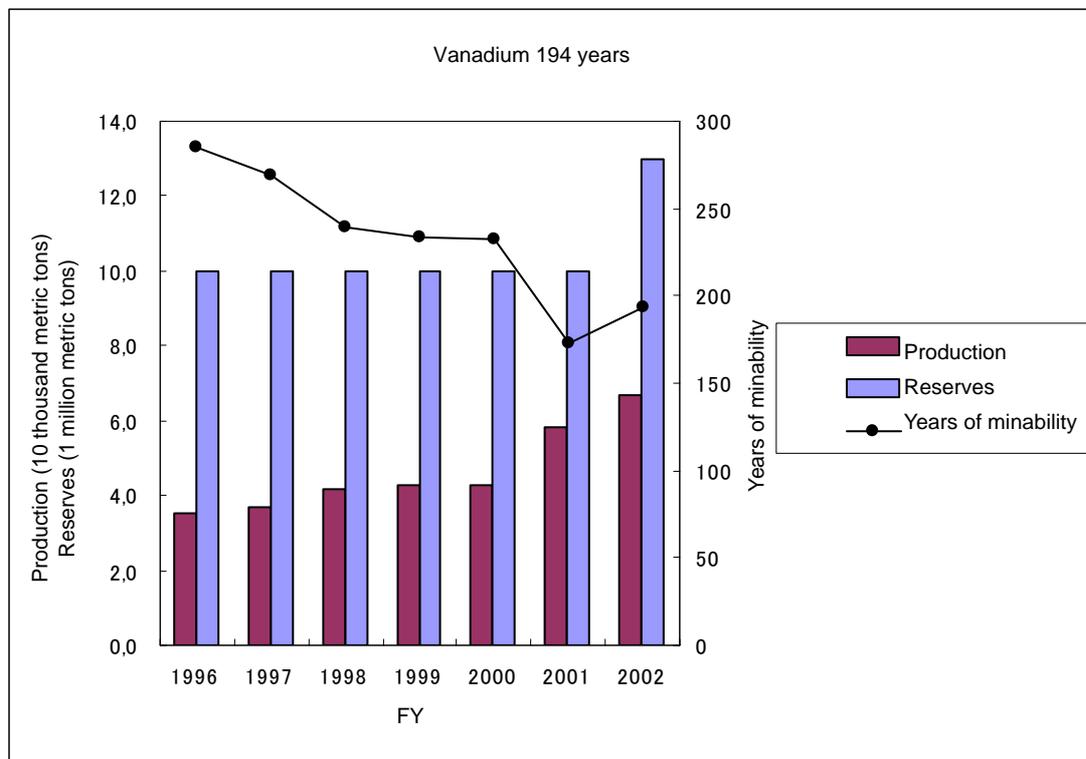
Year	Titanium mineral			Resources (t)
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	
1995				
1996				
1997				
1998	4,260			
1999	4,010	370,000	640,000	230 million
2000	4,700	390,000	660,000	
2001	5,000	380,000	540,000	
2002	4,900	470,000	820,000	

## W Tungsten



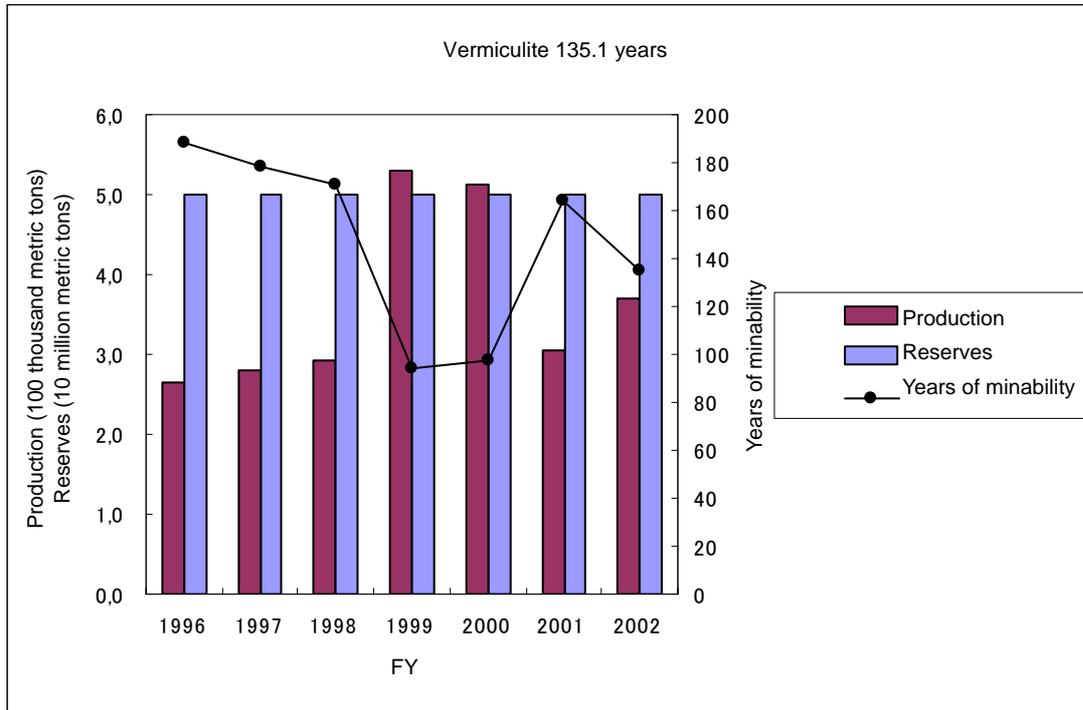
	Tungsten			
	Production (t)	Reserves (t)	Reserve base (t)	Resources
Year				
1995	31,000			
1996	32,000	2,100,000	3,300,000	
1997	33,400	2,100,000	3,300,000	
1998	32,200	2,000,000	3,200,000	
1999	31,000	2,000,000	3,200,000	
2000	37,400	2,000,000	3,200,000	
2001	44,200	1,900,000	3,100,000	
2002	46,600	2,900,000	6,200,000	

## V Vanadium



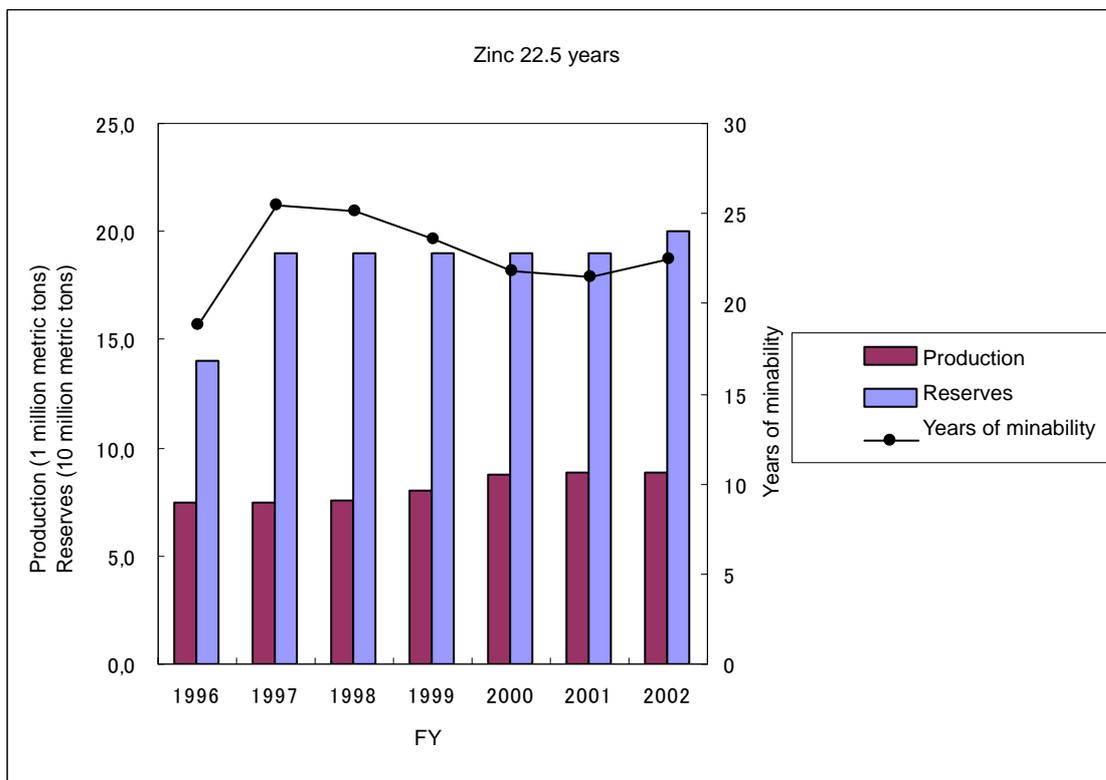
	Vanadium			
	Production (t)	Reserves (t)	Reserve base (t)	Resources (t)
Year				
1995	33,700			
1996	35,100	10,000,000	27,000,000	63 million
1997	37,100	10,000,000	27,000,000	
1998	41,800	10,000,000	27,000,000	
1999	42,800	10,000,000	27,000,000	
2000	43,000	10,000,000	27,000,000	
2001	58,000	10,000,000	27,000,000	
2002	67,000	13,000,000	38,000,000	

## Vermiculite



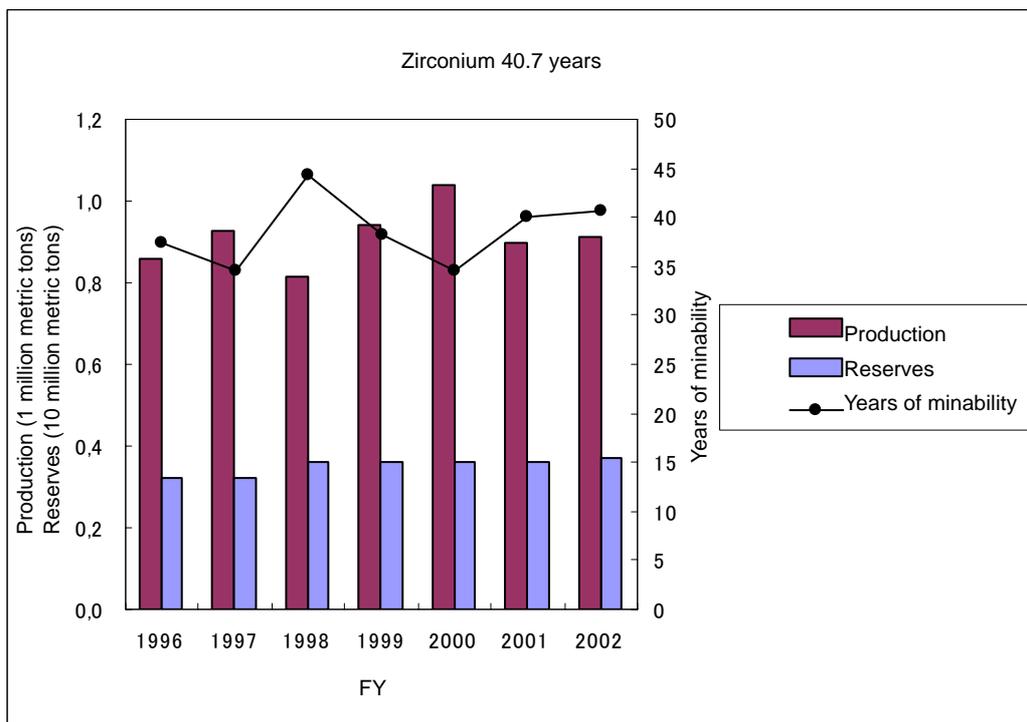
Vermiculite				
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year				
1995	478			
1996	266	50,000	200,000	3 million
1997	280	50,000	200,000	
1998	292	50,000	200,000	
1999	530	50,000	200,000	
2000	512	50,000	200,000	
2001	305	50,000	200,000	
2002	370	50,000	200,000	

Zn Zinc



	Zinc			
	Production (1000 t)	Reserves (1000 t)	Reserve base (1000 t)	Resources (t)
Year	Content			
1995	7,120			
1996	7,440	140,000	330,000	1.8 billion
1997	7,460	190,000	430,000	
1998	7,550	190,000	440,000	1.9 billion
1999	8,040	190,000	430,000	
2000	8,730	190,000	430,000	
2001	8,850	190,000	440,000	
2002	8,900	200,000	450,000	

Zr Zirconium



Zirconium				
	Production (1000 t)	Reserves (1000000 t)	Reserve base (1000000 t)	Resources (t)
Year		ZrO <sub>2</sub>		
1995	897			
1996	857	32	62	60 million
1997	926	32	62	
1998	814	36	65	
1999	940	36	65	
2000	1,040	36	65	
2001	900	36	65	
2002	910	37	72	

#### 4. Characterization Method of the Depletion of Resources

##### 4.1. Investigation of Characterization of the Depletion of Stock Resources

###### 4.1.1. Basic idea for the characteristic value

###### (1) Principle of single numerical expressions

The characteristic value for the environmental impact analysis of LCA can be obtained by multiplying the characteristic coefficient that falls in the specified environmental impact area by the total sum of all the environmental stress factors that were obtained by the inventory analysis for all the systems. That is, the characteristic value of the environmental impact  $k$  for the environmental stress factor  $i$  is:

$$u_{ki} = c_{ki} \times z_i$$

Here,  $c_{ki}$  is the characteristic value of the environmental impact  $k$  on the environmental stress factor  $i$ , and  $z_i$  is the total sum of the system of environmental stress factor  $i$  that were obtained from the inventory analysis.

In addition, the characteristic value of the environmental impact  $k$  that considers all the environmental stress factors can be obtained by:

$$U_k = \sum_i (u_{ki}) = \sum_i (c_{ki} \times z_i).$$

To use this simplified form to perform the calculations, the characteristic coefficients,  $c_{ki}$  must satisfy the following conditions:

- a) have specifications
- b) be additive
- c) be linear
- d) not reach the threshold value.

This means that the environmental impact value  $k$  and the environmental stress factor  $i$  must be expressed by a single specified numerical value.

###### (2) Principle of additivity

For variables which have numerical values, there are intensive variables and extensive variables. Intensive variables are numerical values which do not have any significant meaning when they are added together, such as temperature and density. Extensive variables include numerical values like weights, where each of the values contributes to the total sum. For example, the amount of resource consumption can be used as an extensive variable; however, for the total life of resources, the sum of the total life of resource of 20 years and another with that of 50 years does not add up to a total life of 70 years. Therefore, when working with a numerical value, it is necessary to check whether or not it is an additive extensive variable.

In the environmental impact analysis of LCA, since  $U_k = \sum (c_{ki} \times z_i)$ ,  $c_{ki} \times z_i$  must have the condition of being an additive extensive variable.

###### (2-1) Scientific additivity

Scientific additivity is the case when  $c_{ki} \times z_i$  can be made easily into an extensive variable.

A simple case is when  $U_k$  itself can be expressed as a function of a linear combination of  $z_i$ . A linear combination is when

$$U = a_1 \cdot z_1 + a_2 \cdot z_2 + a_3 \cdot z_3 + a_4 \cdot z_4 + \dots$$

and  $a_1, a_2, a_3, a_4, \dots$  correspond to  $c_1, c_2, c_3, c_4, \dots$ . The amount of suspended substances in the underwater waste matter is an example of this case.

For the actual environmental impact, a synergic impact such as

$$U = U_0 (1 + a_1 \cdot z_1) \cdot (1 + a_2 \cdot z_2) \cdot (1 + a_3 \cdot z_3) \cdot \dots$$

can also be considered instead of the additive relationship shown above. In this case if  $z_i$  is an extremely small value of less than 1, as in the concentration of a very dilute solution, the change in  $U$  becomes

$$U - U_0 = (a_1 z_1 + a_2 z_2 + a_3 z_3 + \dots) + (a_1 a_2 z_1 z_2 + a_1 a_3 z_1 z_3 + \dots) + \dots$$

By neglecting the second and subsequent terms because those terms are extremely small, a linear additivity can be obtained with the remaining first terms. The coefficient of the environmental impact of the atmospheric waste corresponds to the above in most situations.

For cases that are difficult to work with and involve a complex relationship between  $U$  and  $z$ , an approximate linear relationship can be obtained by the partial differential equation.

That is, when  $U = f(x_1, x_2, x_3, \dots)$ ,

$$U = f_0 + (\delta f / \delta x_1) \cdot dx_1 + (\delta f / \delta x_2) \cdot dx_2 + (\delta f / \delta x_3) \cdot dx_3 + \dots$$

By letting  $dx_i$  be the change in the stress factor for taking the specified system and corresponding it to  $z_i$ ,  $U$  is linearized by letting  $c_i = (\delta f / \delta x_i)$ . This method not only uses  $U$  as an extensive variable but also uses it as an intensive variable.

If the previously mentioned evaluation function for depletable resources

$$\text{Evaluation function [1/t]} = \frac{(\text{Speed of consumption [M/t]} - (\text{Speed of regeneration [M/t]})}{(\text{Amount of stock [M]})}$$

is  $U$ , this is an intensive variable since its dimension is inversely related to time, and the partial differential method can be used for scientific applications when necessary.

## (2-2) Expedient additivity

There is also a method to maintain the additiveness of linearity by obscuring the science to some degree. The technique is generally called "weight factor" and is a method which makes it possible to compare case 1,  $\sum(z_i \cdot w_i)$  and case 2,  $\sum(z_i' \cdot w_i)$  by multiplying a "weight coefficient"  $w_i$  based on some standard value to each of the independent terms  $z_i$ . This method is often adopted as an integrated evaluation in LCA, and the weight coefficient  $w_i$  is used to reflect such factors as the degree of importance, the degree of emergency, and the cost.

Looking at this method from a different angle, this method does not place the weight factor on  $z_i$ , but for example uses an evaluation function for importance and adopts  $z_i$  as a variable for the linear relationship of that function. In that case, the evaluation function

$$U = a_1 \cdot z_1 + a_2 \cdot z_2 + a_3 \cdot z_3 + a_4 \cdot z_4 + \dots$$

is considered to be equal to a function that includes some arbitrariness from the person who defined it. In that case it has the following problems:

- 1) The universality of the coefficient becomes one that is based on some mutual artificial agreement and not on a scientific one.
- 2) In addition, putting a weight on the evaluation function  $U$  together with another evaluation function becomes rather difficult.

### (3) Continuity of energy resources and flow resources

This report is targeted towards the depletion of resources (that is, stock resources); however, the necessity to perform the integrated evaluation and the comparison of energy resources and recyclable flow resources easily are also considered to be essential factors in setting up the function of the characteristic value.

#### 4.1.2. Characteristic coefficient of depletable resources as a weight factor

There are methods of using the variables that express the depletion of resources as weight factors. They include the following:

- (1) Method of using the reciprocal number of reserves as the weight coefficient.
- (2) Method of using the reciprocal number of the total lifespan as the weight coefficient.
- (3) Method of using the product of the reciprocal number of reserves and the reciprocal number of the total lifespan as the weight coefficient.
- (4) Method of using the consumed amounts.
- (5) Method of using the difference between the crustal concentration and the share of the present productivity.

Methods (1), (2) and (3) basically depend on the data of reserves and the life. They are summarized in the table shown below. The numerical values are based on iron, and the characteristic coefficients correspond to the quantity of iron. Elements with \* were not included in the latest database of USGS and were obtained from other sources.

Element	Unit (t/y)	Annual production	Reserves (R)	Years of minability (YM)	Iron-standard 1/R	Iron-standard 1/YM	Iron-standard 1/R·YM
Ag	1	18,800	270,000	14.4	259,259.26	8.10	2,101,080.25
As*	1	35,000	800,000	22.9	87,500.00	5.10	445,906.11
Au	1	2,530	42,500	16.8	1,647,058.82	6.95	11,441,176.47
Al	1000	141,000	22,000,000	156	3.18	0.75	2.38
Be*	1	200	19,000	95	3,684,210.53	1.23	4,525,761.77
Bi	1	3,900	330,000	84.6	212,121.21	1.38	292,606.92
Br*	1000	520	15,400	29.6	4,545.45	3.94	17,920.76
Cd	1	18,700	600,000	32.1	116,666.67	3.64	424,143.30
Co	1	36,900	6,700,000	181.6	10,447.76	0.64	6,713.95
Cr	1000	13,000	1,600,000	123.1	43.75	0.95	41.48
Cu	1000	13,400	480,000	35.8	145.83	3.26	475.38
Fe	1000000	600	70,000	116.7	1.00	1.00	1.00
Ge*	0.001	6,800	500,000	73.5	140,000,000.00	1.59	222,285,714.29
Hg	1	1,400	120,000	85.7	583,333.33	1.36	794,340.72
In	1	335	2,500	7.5	28,000,000.00	15.56	435,680,000.00
Li	1	15,100	4,100,000	271.5	17,073.17	0.43	7,338.63
Mg	1000	2,980	2,100,000	704.7	33.33	0.17	5.52
Mn	1000	7,600	300,000	39.5	233.33	2.95	689.37
Mo	1	128,000	8,600,000	67.2	8,139.53	1.74	14,135.17
Nb	1	25,700	4,400,000	171.2	15,909.09	0.68	10,844.57
Ni	1	1,320,000	61,000,000	46.2	1,147.54	2.53	2,898.66
Pb	1000	2,900	68,000	23.5	1,029.41	4.97	5,112.02
Pts	0.001	171,000	71,000,000	415.2	985,915.49	0.28	277,110.64
REO	1	85,500	88,000,000	1,029.20	795.45	0.11	90.20

Re	0.001	23,100	2,400,000	103.9	29,166,666.67	1.12	32,759,865.26
S	1000	58,000	1,300,000	22.4	53.85	5.21	280.53
Sb	1	141,000	1,800,000	12.8	38,888.89	9.12	354,557.29
Se	1	1,460	84,000	57.5	833,333.33	2.03	1,691,304.35
Sn	1	230,000	6,100,000	26.4	11,475.41	4.42	50,726.53
Sr	1	360,000	6,800,000	18.9	10,294.12	6.17	63,562.09
Ta	1	1,530	39,000	25.5	1,794,871.79	4.58	8,214,177.98
Te	1	130	21,000	161.5	3,333,333.33	0.72	2,408,668.73
Tl	1	15	380	25.3	184,210,526.32	4.61	849,698,356.56
Ti	1000	490	47,000	95.9	1,489.36	1.22	1,812.39
V	1	67,000	13,000,000	194	5,384.62	0.60	3,239.10
W	1	46,600	2,900,000	62.2	24,137.93	1.88	45,287.73
Zn	1000	8,900	200,000	22.5	350.00	5.19	1,815.33
Zr	1000	910	37,000	40.7	1,891.89	2.87	5,424.66

In the method using the consumed amounts (4),

$$[\text{Amounts of resources}] = [\text{Produced amount}] + [\text{Reserves}],$$

$$[\text{Consumption rate of resources}] = [\text{Produced amount}] / [\text{Amounts of resources}] \\ = [\text{Produced amount}] / ([\text{Produced amount}] + [\text{Reserves}]).$$

The rate of resource consumption is an important means of determining the degree of importance of resource depletion.

The advantages of this method include

- a) negligible factors such changes in current production volume because cumulative production is considered, and
- b) the equivalent of 100% depletion can also be considered, and it is easy to get a general idea of the level of depletion of each resource.

Problem points include

- a) cumulative data on production are required, but it is difficult to acquire accurate data on resources like iron and copper that have a long history of use, and
- b) as with other methods, the amount of unused resources is calculated from the reserves, but the numerical value of reserves can be affected greatly by economic and technological changes.

The following table is an example of estimation based on the data of 1987.

	Produced amount Mt ('87)	Reserves MT ('87)	Consumption rate of resource	Iron-standard
Fe	16113	66100	0.196	1.00
Al	380	4250	0.082	0.42
Cr	79.1	418	0.159	0.81
Cu	247	352	0.412	2.10
Zn	204	147	0.581	2.97
Mn	268	812	0.248	1.27
Pb	124.7	70	0.640	3.27
Ni	22	48.6	0.312	1.59

Sr	2.68	7	0.277	1.41
Mg	90.1	2500	0.035	0.18
Sn	9.92	4.28	0.699	3.56
Ag	0.401	0.28	0.589	3.00
Sb	2.7	4.2	0.391	2.00
Mo	2.74	5.53	0.331	1.69
Ti	51.2	170	0.231	1.18
U	0.32	0.83	0.278	1.42
V	0.716	4.27	0.144	0.73
Co	0.996	3.31	0.231	1.18
W	1.85	2.57	0.419	2.14
Nb	0.27	3.55	0.071	0.36
Bi	0.141	0.09	0.610	3.11
Zr	7.26	26.6	0.214	1.09
Li	0.84	2.21	0.275	1.41
Au	0.059	0.042	0.584	2.98
Hg	0.27	0.126	0.682	3.48
Ta	22	0.022	0.999	5.10
Be	0.005	0.013	0.278	1.42
Pt	0.005	0.056	0.082	0.42
Th	0.38	1	0.275	1.40

The method (5) views differences between crustal concentration and the present share of production in order to express the degree of resource depletion while avoiding the technology and economic changeability.

This method can derive the proportion in the present annual production amount for some elements and derive the ratio to the amount that is in the earth crust.

This value is a number which indicates how much of the element can be concentrated and used at the current production rate based on the amount in the earth crust. The larger the ratio, the greater the pressure on original resources that are still in the earth crust.

The advantages of this method are

- a) characteristic coefficients of depletable resources can be calculated based on the production volume and the crustal concentration which are objective numerical values, and
- b) the imbalance between the global environment and human resource use can be understood numerically.

Problem points include

- a) it is not directly linked to direct resource depletion, and
- b) trace elements and currently unused resources show small values, so there is a danger that there might be a misvaluation of resources which are experiencing rapid growth in new applications.

The table below shows proportions of rate of production to rate of existing amount in the earth crust.

	Annual production (t/y)	Rate of production ( $\times 10^6$ )	Existing amount in the crust (ppm)	Rate of existing amount in the crust ( $\times 10^6$ )	Rate of production/ Rate of existing amount in the earth crust	Iron-standard
Fe	571,000,000.00	883674.322	50000.000	114669.759	7.706	1.000
Al	23,900,000.00	36987.419	81300.000	186453.028	0.198	0.026
Cr	13,700,000.00	21201.993	100.000	229.340	92.448	11.996
Cu	12,900,000.00	19963.921	55.000	126.137	158.272	20.538
Zn	8,000,000.00	12380.726	70.000	160.538	77.120	10.008
Mn	7,450,000.00	11529.551	950.000	2178.725	5.292	0.687
Si	3,400,000.00	5261.809	277200.000	635729.145	0.008	0.001
Pb	2,980,000.00	4611.820	13.000	29.814	154.686	20.073
Ni	1,230,000.00	1903.537	75.000	172.005	11.067	1.436
Sr	304,000.00	470.468	375.000	860.023	0.547	0.071
Mg	284,000.00	439.516	20900.000	47931.959	0.009	0.001
Sn	200,000.00	309.518	2.000	4.587	67.480	8.757
Ag	160,000.00	247.615	0.070	0.161	1542.408	200.150
Sb	121,000.00	187.258	0.200	0.459	408.256	52.977
Mo	112,000.00	173.330	1.500	3.440	50.385	6.538
Ti	51,000.00	78.927	4400.000	10090.939	0.008	0.001
U	45,807.00	70.890	1.800	4.128	17.173	2.228
V	42,000.00	64.999	135.000	309.608	0.210	0.027
As	40,000.00	61.904	1.800	4.128	14.996	1.946
Ce	35,014.00	54.187	60.000	137.604	0.394	0.051
Co	32,300.00	49.987	25.000	57.335	0.872	0.113
W	31,500.00	48.749	1.500	3.440	14.171	1.839
Nb	23,600.00	36.523	20.000	45.868	0.796	0.103
Cd	19,300.00	29.869	0.200	0.459	65.119	8.450
La	18,860.00	29.188	30.000	68.802	0.424	0.055
Bi	17,900.00	27.702	0.200	0.459	60.395	7.837
Zr	14,250.00	22.053	165.000	378.410	0.058	0.008
Nd	13,940.00	21.573	28.000	64.215	0.336	0.044
Li	13,000.00	20.119	20.000	45.868	0.439	0.057
B	4,270.00	6.608	2.800	6.422	1.029	0.134
Pr	3,362.00	5.203	8.200	18.806	0.277	0.036
Sm	2,460.00	3.807	6.000	13.760	0.277	0.036
Au	2,445.00	3.784	0.004	0.009	412.474	53.525
Y	2,400.00	3.714	33.000	75.682	0.049	0.006
Yb	1,958.00	3.030	3.000	6.880	0.440	0.057
Hg	1,800.00	2.786	0.080	0.183	15.183	1.970
Gd	1,640.00	2.538	5.400	12.384	0.205	0.027
Se	1,400.00	2.167	0.050	0.115	18.894	2.452
Dy	656	1.015	4.800	11.008	0.092	0.012
Tb	574	0.888	0.800	1.835	0.484	0.063
Br	520	0.805	2.500	5.733	0.140	0.018
Ta	513	0.794	2.000	4.587	0.173	0.022
Be	356	0.551	2.800	6.422	0.086	0.011

Er	246	0.381	2.800	6.422	0.059	0.008
In	220	0.340	0.100	0.229	1.485	0.193
Ga	210	0.325	15.000	34.401	0.009	0.001
Pt	178	0.275	0.010	0.023	12.011	1.559
Pd	177	0.274	0.010	0.023	11.944	1.550
Te	125	0.193	0.010	0.023	8.435	1.095
Hf	123.5	0.191	3.000	6.880	0.028	0.004
Lu	114.8	0.178	0.500	1.147	0.155	0.020
Ho	98.4	0.152	1.200	2.752	0.055	0.007
Eu	82	0.127	1.200	2.752	0.046	0.006
Tm	65.6	0.102	0.500	1.147	0.089	0.011
Ge	58	0.090	1.500	3.440	0.026	0.003
Th	45	0.070	7.200	16.512	0.004	0.001
Re	43	0.067	0.001	0.002	29.017	3.765
Rh	23.96	0.037	0.005	0.011	3.234	0.420
Ru	19.99	0.031	0.010	0.023	1.349	0.175
Ir	3.18	0.005	0.001	0.002	2.146	0.278
Os	0.06	0.000	0.001	0.002	0.040	0.005

#### 4.1.3. Characteristic coefficients of depletion of resources for scientific characterization

It is necessary to start with the evaluation function to determine the characteristic coefficient in a scientific manner.

The evaluation function for the depletion of resources can be considered to be:

$$\text{Evaluation function [1/t]} = \frac{(\text{Consumption rate [M/t]} - (\text{Regeneration rate [M/t]}))}{(\text{Amount of stock [M]})}$$

A superior aspect of this function is that it can be used for both flow and stock resources

This evaluation function is the reciprocal number of time and will hereafter be called "resource depletion rate, V".

Here, when only  $\Delta z_i$  of resource i is consumed, the resource depletion rate V must be considered. That is, if

$D_i$ : Consumption rate of resource i [ton/year] and

$R_i$ : Amount of stock of resource i. [ton],

then the change in V is as follows:

$$\Delta V = \frac{D_i + \Delta z_i}{R_i - n \cdot \Delta z_i} - \frac{D_i}{R_i}$$

Furthermore, n is the targeted period [year]. If the top and bottom are divided by  $R_i$  and the second term of the denominator is ignored from the relationship of  $R_i \gg n \cdot \Delta z_i$ , the equation becomes

$$\frac{D_i + \Delta z_i}{R_i - n \cdot \Delta z_i} - \frac{D_i}{R_i} = \frac{\Delta z_i \cdot (R_i + n \cdot D_i)}{R_i \cdot (R_i + n \cdot \Delta z_i)}$$

$$\doteq \frac{\Delta z_i}{R_i} \cdot \left(1 + \frac{n \cdot D_i}{R_i}\right)$$

By using the total life of the resource ( $R_i/D_i$ ), i.e.,  $\lambda_i$  [year], the above equation is expressed as follows:

$$= \frac{\Delta z_i}{R_i} \cdot \left(1 + \frac{n}{\lambda_i}\right)$$

In this case, the coefficient  $c_i$  is used to correspond to  $z_i$ , which is scientifically reasonable.

$$c_i = \frac{K}{R_i} \cdot \left(1 + \frac{n}{\lambda_i}\right)$$

This is a numerical value showing how quickly the resource depletion proceeds, thus it is appropriate to call it “acceleration of resource depletion.” Furthermore,  $K$  is a constant that is unrelated to  $i$  and is used to simplify the understanding through the organization of digits.

Here,  $n$  is the period that is applicable for technology. Basically,  $n$  depends on the production plan of the product that is being considered, but it is necessary to provide a fixed value that is not related to  $i$  if it is to be used as a coefficient. If we consider the evaluation for the environmental impact for the productivity in which the durability of LCA'S target is possible, a certain length of period is necessary. Thus, for the moment, an upper limit of 100 years has been established to discuss the possibility for durability.

At the moment, resources with low depletion such as iron have a total life of more than 100 years, thus setting  $n = 100$  is considered to be reasonable since the first terms in these resources will become the dominating terms.

Mathematically, the calculations that have been shown thus far include taking the partial differential of  $V$  with respect to  $z_i$ . That is,

$$\frac{\delta V}{\delta z_i} = \frac{1}{R_i} \cdot \left(1 + \frac{n}{\lambda_i}\right)$$

and the intensive variable was linearized by taking the partial differential of (2-1) in Section 4.1.1.

To use the acceleration of the resource depletion

$$c_i = \frac{K}{R_i} \cdot \left(1 + \frac{n}{\lambda_i}\right)$$

as the characteristic coefficient, it is necessary to determine a constant  $K$  to simplify the use of the numerical values that have been assigned specific characteristic values.

Of course there is essentially no problem if  $K = 1$ , and in that case  $c_i \cdot z_i$  indicates the increase in the consumption of resource  $i$  by  $z_i$ , and the continuous usage for  $n$  years indicates the ratio for

increasing the acceleration of depletable resources.

At first,  $K = 1$  appears to be meaningful, but it is actually a variable whose image is difficult to comprehend. Therefore, it should be shown as an equivalent expression of another characteristic value. Equivalent expression can be described as a method that selects a standard amount using a certain component and substituting another component's amount with an equal value to the original component. For example, to obtain the coefficient of global warming, a characteristic value can be obtained based on a certain amount of  $\text{CO}_2$  for a totally different component.

In the evaluation of the depletion of resources, it is appropriate to consider iron as the standard because it represents the production of the modern times, is abundant, and has the complete set of data on the reserve of resources.

That is, the characteristic value of the depletion of resources can be expressed as "the acceleration of the depletion of resources that equals the use of many tons of iron".

Here, if

$$c_{\text{Fe}} = \frac{1}{R_{\text{Fe}}} \cdot \left( 1 + \frac{n}{\lambda_{\text{Fe}}} \right)$$

then, the characteristic coefficient for the depletion of resource  $i$ ,  $C_i$ , is:

$$C_i = \frac{1}{c_{\text{Fe}} \cdot R_i} \cdot \left( 1 + \frac{n}{\lambda_i} \right)$$

In other words, it becomes

$$C_i = \frac{R_{\text{Fe}}}{R_i} \cdot \left( 1 + \frac{n}{\lambda_i} \right) / \left( 1 + \frac{n}{\lambda_{\text{Fe}}} \right)$$

#### 4.1.4. Table for characteristic coefficients

Values of  $R_{\text{Fe}}/R_i$ ,  $\lambda_i$ , and  $\lambda_{\text{Fe}}$  are required to obtain this  $C_i$  value.  $R_{\text{Fe}}/R_i$  is the ratio of the amount of the stock of the resource, and the value for the lifetime  $\lambda$  can be obtained from the data of UGSG, but this  $\lambda$  is also affected by the condition of the data on the reserves. The parts of the reserve data with lots of ambiguity are limited to resources with long lifetimes, and investigations towards the resources with short lifetimes are being conducted rather rigorously partly for economic reasons. The value for the lifetime  $\lambda$  for this characteristic value is utilized in the form of  $1/\lambda$ , and we can see that the longer the lifetime and the more the data becomes ambiguous, the smaller the influence towards the characteristic value gets.

In particular, for the resources where the reserves cannot be specified because it is utilized from seawater, the value  $(1 + n/\lambda_i)$  can be approximated to be 1, and  $C_i$  can be obtained for resources such as rare earth and platinum groups which have limited data.

Therefore,

- a) In principle, the amount of stock is considered to be the reserve, i.e., the amount of utilized resource in the area of economic activities.
- b) When the amount of reserve  $i$  is not determined,  $R_i$  and  $R_{\text{Fe}}$  are dealt with as amounts of stock to estimate the  $C_i$  value.
- c) Even when the reserve can be specified in a),  $R_i$  and  $R_{\text{Fe}}$  are used under the condition that the reserves may only be investigated when the  $C_i$  value in b) is small.

The characteristic coefficients for the acceleration of resource depletion for various metallic resources are shown on the next page.

#### 4.1.5. Correction of the total amount of materials involved

The total amount of materials involved that was shown in the previous “Category characterization coefficients for "Utilization of Mineral Resources" are numerical values taken directly from “Total amount of ores” listed in the 2001 J. Japan Inst. Metals. The “Total amount of ores” refers to the amount of metallic component involved that is absolutely included in the ore as a resource and is mainly equivalent to the amount of stripped soils, gangues, etc., produced during excavation. The amount of materials, energy, etc., used to extract the metallic components is not included in the calculations.

Therefore, in the case of metals, the total amount of materials involved are integrated based on a versatile ingot amount, which includes the energy inputs during excavation, smelting from the dressing process onward, and the extraction process.

In addition, previous amount of ores involved do not include secondary materials that are often contained in metallic ores, such as silver, gold, etc., that is obtained from copper smelting, with calculations made for grades as a single ore. However, in actual mines, there are numerous cases where different metallic components are extracted from the same ore, so the new calculations considered cases where several components would exist in the same ore.

As a result, a method called “allocation” was employed in the LCA, with “economic allocation” used depending on the price that was ultimately calculated for ingots. It should be noted that this method corresponds to the JIS method for calculating the amount of ore in a mine.

According to the order of processes, the allocation is described firstly.

The “calculations for total amount of ore involved” mentioned previously include calculations for the amount of ore involved in 3 levels of refining. They are:

Level 1: Based on statistical data of actual operations

The data for total extracted volume, which includes stripped soils, waste soil, etc., produced during actual operations and the component volume data for the ultimately shipped ore make up the total amount of materials involved which is derived from the statistical processing for each mine.

Level 2: Based on statistical data from actual operations

Based on the results of Level 1 and the grade data from each mine, the stripped soil ratio was estimated to be 3 for the amount of materials involved.

Level 3: Based on statistical data from actual operations

The amount of materials involved was derived from grade of raw ore estimated from the degree of occurrence in the earth’s crust.

However, the targets of allocation were levels 1 and 2, so allocation was conducted for the components of all excavated earth, including stripped soils and waste soils for each mine. Total excavated earth was allocated to each component, and each component was treated as existing in its own mine.

Assuming the total excavated earth from mine  $j$  is  $W_j$ , the production of component  $i$  is  $y_{i,j}$ , and the price of component  $i$  is  $p_i$ , the allocated amount of excavation is expressed as follows:

$$w_{i,j} = \frac{W_j * y_{i,j} * p_i}{\sum(y_{i,j} * p_i)}$$

From this equation, we can clearly see that

$$W_j = \sum w_{i,j}$$

where the excavated amount is proportioned for all components.

The added calculation of materials involved which include energy inputs is a rough estimate based on the rough calculation of above-mentioned ore involved. Therefore, there was no careful examination of the process, only a rough estimate was made to give an general idea of the situation.

Consequently, a different energy source had been used for each process. However, here we decided to ignore differences in energy sources in deriving energy units for the smelting and extraction processes. This resource unit was multiplied by the resource inputs for unit energy derived from the world average energy consumption ratio to obtain the amount of materials involved in energy inputs.

The energy units for the smelting and extracting processes of each component were as follows:

Level A: Obtained from processed LCA inventory data, etc.

Fe, Cu, Pb, Zn and Al were based on data from the Society of Non-Traditional Technology

Level A': Mainly used as ferroalloys, obtained from processed LCA inventory data, etc.

Were obtained from ferroalloy smelting data for Cr, Ni, Co, Mn, Si, V, Nb, Mo, W based on data from the Society of Non-Traditional Technology.

Level B: Obtained from reference data

From "Calculations of Environmental Load at the Smelting Stage of Metallic Element" by the EcoMaterials Centre, National Institute for Materials Science

Li, Mg, Ca, Ti, Ag, Cd, In, Sn, Sb, Ta, Au

Level C: Because there were no clear energy input data related to smelting and extraction, an estimate was made based on thermodynamic data.

It should be noted that at Level C, the resource unit data from Level A to Level B were plotted against the theoretical values (the standard enthalpy needed to maintain the melting temperature of the extracted metal plus the standard free energy change for reducing the metal from the main compound). The actual required energy inputs were 10 to 100 times higher than the theoretical values. As a result, it was estimated that energy inputs 10 times higher than the minimum theoretical value would be needed.

The values obtained above are given on the following page as the geometric means of the resource depletion coefficient, and the resource depletion coefficient and amount of materials involved when iron was 1.

		TMR	Resource depletion coefficient	Geometric mean (Fe: 1)		TMR	Resource depletion coefficient	Geometric mean (Fe: 1)	
3	Li	1,500	1,800	580	52	Te	270,000	2,900,000	300,000
4	Be	2,500	21,000	2,600	57	La	3,100	470	420
5	B	140	9,600	400	58	Ce	2,000	450	330
11	Na	50			59	Pr	8,000	3,300	1,800
12	Mg	70	1.5	3.6	60	Nd	3,000	1,000	600
13	Al	48	0.37	1.5	62	Sm	9,000	4,500	2,200
14	Si	34	0.10	0.6	63	Eu	20,000	22,000	7,400
20	Ca	90			64	Gd	10,000	5,000	2,500
21	Sc	2,000			65	Tb	30,000	34,000	11,000
22	Ti	36	12	7.4	66	Dy	9,000	6,500	2,500
23	V	1,500	300	240	67	Ho	25,000	22,000	8,300
24	Cr	26	43	12	68	Er	12,000	9,600	3,800
25	Mn	14	100	13	69	Tm	40,000	54,000	16,000
26	Fe	8	1	1	70	Yb	12,000	9,000	3,600
27	Co	600	1,600	350	71	Lu	45,000	54,000	17,000
28	Ni	260	1,100	190	72	Hf	10,000	9,000	3,300
29	Cu	360	300	110	73	Ta	6,800	66,000	7,400
30	Zn	36	1,000	67	74	W	190	34,000	890
31	Ga	14,000	1,800	1,800	75	Re	20,000	30,000,000	270,000
32	Ge	120,000	18,000	16,000	76	Os	540,000	27,000,000	1,300,000
33	As	29	15,000	230	77	Ir	400,000	27,000,000	1,100,000
34	Se	70	1,200,000	3,200	78	Pt	520,000	660,000	210,000
35	Br2	9,400	10,000	3,500	79	Au	1,100,000	6,200,000	920,000
37	Rb	133			80	Hg	2,000	680,000	13,000
38	Sr	500	450	170	82	Pb	28	2,900	100
39	Y	2,700	1,200	630	83	Bi	180	250,000	2,300
40	Zr	550	560	190	88	Ra	280,000,000		
41	Nb	640	2,100	400	90	Th	9,000	3,700	2,000
42	Mo	750	11,000	1,000	92	U	22,000	32,000	9,300
44	Ru	80,000	2,700,000	160,000	coal	12	0.04	0.2	
45	Rh	2,300,000	5,400,000	1,200,000	oil	7.4	0.8	0.9	
46	Pd	810,000	2,700,000	520,000	Crushed rock	1.4			
47	Ag	4,800	1,100,000	25,000	Aggregate	1.4			
48	Cd	7	260,000	450	plastic	10	0.8	1.0	
49	In	4,500	3,900,000	46,000	Wood	8.0	0.24	0.5	
50	Sn	81	30,000	540	cement	3.2			
51	Sb	42	180,000	970	Grain	330	19	27	

Mine statistical data and energy data in actual operation

Ore grade of actual mine and energy data in literatures

Grade estimation from crustal concentration and energy data in literatures

Stock estimation from crustal concentration (no reserve data)

Stock estimation from crustal concentration (values less than values estimated using reserves)

Stock estimation from reserves (values less than values estimated using crustal concentration)

Stock estimation from resources and recycled rate (resources = -consumption rate + recycling rate)

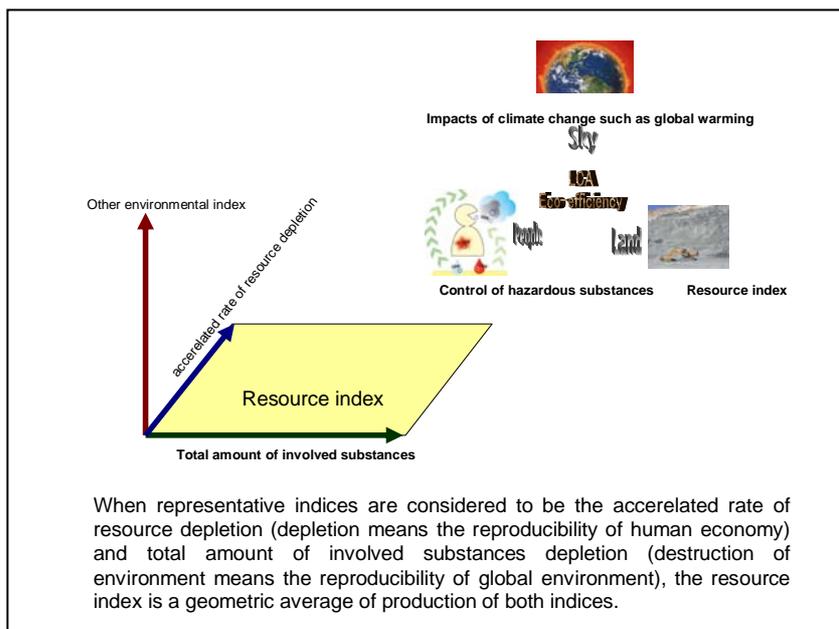
	TMR	資源枯渇係数	幾何平均(Fe=1)	
3	Li	1,500	1,800	580
4	Be	2,500	21,000	2,600
5	B	140	9,600	400
11	Na	50		
12	Mg	70	1.5	3.6
13	Al	48	0.37	1.5
14	Si	34	0.10	0.6
20	Ca	90		
21	Sc	2,000		
22	Ti	36	12	7.4
23	V	1,500	300	240
24	Cr	26	43	12
25	Mn	14	100	13
26	Fe	8	1	1
27	Co	600	1,600	350
28	Ni	260	1,100	190
29	Cu	360	300	110
30	Zn	36	1,000	67
31	Ga	14,000	1,800	1,800
32	Ge	120,000	18,000	16,000
33	As	29	15,000	230
34	Se	70	1,200,000	3,200
35	Br2	9,400	10,000	3,500
37	Rb	133		
38	Sr	500	450	170
39	Y	2,700	1,200	630
40	Zr	550	560	190
41	Nb	640	2,100	400
42	Mo	750	11,000	1,000
44	Ru	80,000	2,700,000	160,000
45	Rh	2,300,000	5,400,000	1,200,000
46	Pd	810,000	2,700,000	520,000
47	Ag	4,800	1,100,000	25,000
48	Cd	7	260,000	450
49	In	4,500	3,900,000	46,000
50	Sn	81	30,000	540
51	Sb	42	180,000	970

## 5. Handling as Resource Indices

Important considerations when making calculations of LCA, environmental effects, etc., were how to treat environmental load categories, that is, the importance of reflecting environmental awareness in evaluating environmental load. In Japan, it is easy to obtain and calculate data, so the impact of global warming substances such as CO<sub>2</sub> is often used as an evaluation function. However, environmental issues, such as creating a recycling society and effective utilization of materials and resources, are not strictly the realm of global warming.

At the very least, the three perspectives of Sky (atmospheric changes such as global warming), Land (resource indices), and People (control of chemical substances, effect on health and living organisms) can, according to the discussion, be used to derive LCA, environmental efficiency, and so on.

From these perspectives, it would be preferable if the acceleration of resource depletion (which affects the recycling base of economic activities) and the amount of materials involved (which is an indicator of the impact on the recycling base of the global environment) could be expressed simply as resource indices.



While both of these indices are basically dependent on the scarcity of the resource, they both have effects on the various elements involved in the global environment and the achieving a sustainable economy. As a result, they are considered to be vectors to individual axes. The extent of these vectors' overall influence is represented by their product, area. Furthermore, by using their square roots as geometric means, these vectors may be projected as one axis to reflect the common trait that is scarcity of the resource.

This is one concept of this simplification method. Although it will have to be investigated further, the simple methodology is one of its attractive points.

This index is an environmental load factor that is related to resource use. However, it is also an index for showing the value of a resource which is indispensable for people even paying the cost for environment.

Therefore, when using this resource index for actual resource management, it makes the user think of the relation with cost. As a result, a plot was made of the relation with the index and cost. It is shown on the next page. For reference, the slope of the line which connects iron and grain in plots is approximately 1. In other words, this has a directly proportional relation with cost. Most metallic elements show a slight deviation (in which cost is lower than the index), but it does reflect cost to a certain extent.

It should be noted that when the cost is plotted against acceleration of resource depletion, where the acceleration of resource depletion is large, it is a square of cost, that is exponentially greater than cost, which may be quite different than one may expect.



This resource index is not merely a factor of environmental load, but it also shows the preciousness of a resource. It must be easy to use so that it can be employed to examine resource productivity, develop products that make full use of the resources, and manage a recycling system, among other things.

When managing actual products, it can be used to estimate what degree of quantitative understanding is necessary. For this purpose, these indices should be simplified to about significant one-digit numerical values. Furthermore, it was decided to group the same level of numerical values together to clarify which level is the target of management.

Results derived in this way are listed in the following table. Numbers in parentheses suggest the management level to be included in the product.

Gold group (0.01 mg/kg)		Silver group (1 mg/kg)		Tin group (10 mg/kg)		Copper group (0.1 g/kg)		Iron group (1 g/kg)	
Os	1000000	Te	300000	Er	3000	Cd	400	Mn	13
Rh	1000000	Re	200000	Yb	3000	La	400	Cr	12
Ir	1000000	Pt	200000	Br2	3000	Nb	400	Ti	7.4
Au	1000000	Ru	200000	Hf	3000	B	400	Mg	3.6
Pd	500000	In	50000	Se	3000	Co	300	Al	1.5
		Ag	25000	Be	2000	Ce	300	Fe	1
		Lu	10000	Dy	2000	V	200	Si	0.6
		Ge	10000	Gd	2000	As	200		
		Tm	10000	Bi	2000	Zr	200		
		Hg	10000	Sm	2000	Ni	200		
		Tb	10000	Th	2000	Sr	200		
		U	10000	Pr	2000	Cu	120		
		Ho	8000	Ga	2000	Pb	100		
		Ta	8000	Mo	1000	Zn	70		
		Eu	8000	Sb	1000				
				W	1000				
				Y	600				
				Nd	600				
				Li	600				
				Sn	500				

**Element group classified based on the resource index**  
(X g/kg) means an approximate value of lower control limit in product

The above report is a revision of “Coefficients for Numerically Characterizing Mineral Resource Use Categories.” We are improving this report to aim a perfect version, including reexaminations of numerical values and reflection of the opinions and inputs of numerous collaborators.

March, 2005  
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