MINING AND EXPLORATION FOR MINERAL RESOURCES

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Summary

Depletion of mineral resources often induces social crises and sometimes causes wars. However, during the long history of human beings, total depletion of a single mineral has never occurred. New discoveries and technology are adding to the reserves of various mineral commodities at a rate that has exceeded depletion. Mineral exploration leading to the discovery of new ore deposits and products is one of the most important forces helping to fend off depletion. In section 1, the fundamentals and aims of mineral exploration are briefly introduced. In section 2, the characteristics and formative processes of mineral deposits are described for geologic prospecting. In sections 3 and 4, the geophysical and geochemical prospecting methods widely used for mineral explorations are described.

1. Introduction

The magnitude of the world's mineral production has increased sharply, and there is no sign that this growth is likely to stop in the near future. The growth rates of production and life expectancies of aluminum, crude steel, copper, zinc and energy over the past half century are illustrated in Figure 1.

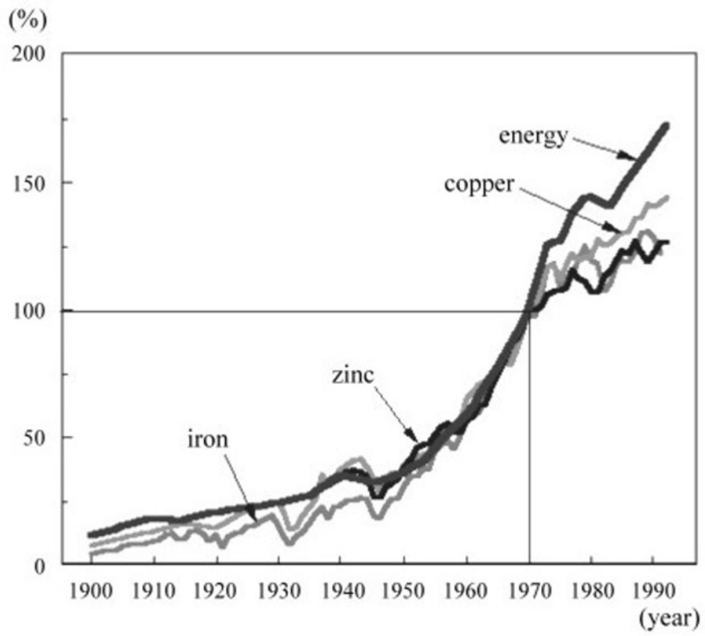

Figure 1: Growth Rates of Energy, Iron, Copper and Zinc (1970=100)
(by Nishiyama, T. (1998). Trends and Prospects for Supply of Energy and Minerals Energy and Resources, Vol.19, No1, p.23.)

Growth rates increased radically after 1950, especially between 1950 and 1973. On the other hand, life expectancies have remained nearly constant because new discoveries and technology add to the reserves of mineral commodities at a rate that has exceeded depletion, in order to satisfy growing demands. However, since the quantity of a particular resource in the Earth's crust is physically limited, it is questionable whether this condition is sustainable in the future. Therefore, most of our attention for the future has been focused on potentially recoverable resources and exploration (see *Mining Engineering and Mineral Transportation*).

Reserves, production and life expectancies are fundamental factors in forecasting the supply and demand of mineral commodities. Current statistical data for 35 minerals are summarized in Table 1.

Element	Unit	Production	Reserve	Lifetime	Price	Resources principal (P)	
		(P)	(R)	(R/P)	(US$/kg)		
Al	1000t	130,619	25,000,000	191	1.45	Guinea (13%)	Jamaica (9%)
Sb	t	73,762	2,100,000	28	1.39	China (60%)	Russia (17%)
As	t	46,800	1,000,000	21		China (38%)	Frence (13%)
Be	t	6,220	N.A.	N.A.	720.9	U.S.A. (82%)	Russia (16%)
Bi	t	3,620	110,000	30	8.49	Mexico (35%)	Peru (28%)
B	1000t	4,817	170,000	35	0.37	Turkey (32%)	U.S.A (28%)
Cd	t	18,764	600,000	32	0.31	Japan (14%)	Canada (11%)
Cr	1000t	14,000	3,700,000	264	0.063	South Africa (49%)	Kazakhstan (17%)
Co	t	29,900	4,500,000	151	37.52	Congo (23%)	Canada (18%)
Cu	1000t	12,288	340,000	28	1.67	Chile (30%)	U.S.A. (15%)
Au	kg	2,540,000	45,000,000	18	9000	South Africa (18%)	U.S.A. (13%)
In	t	N.A.	2,600	N.A.	303		
Fe	1000t	1,041,571	74,000,000	71	0.025	China (25%)	Brazil (18%)
Pb	1000t	2,977	66,000	22	0.96	Australia (23%)	China (18%)
Li	1000t	N.A.	3,400	N.A.	4.47		
Mn	1000t	20,400	680,000	33	2.26	South Africa (15%)	Gabon (10%)
Hg	t	3,663	120,000	33	4.06	Spain (37%)	Russia (30%)
Mo	1000t	142	5,500	39	5.9	U.S.A. (38%)	China (23%)
Ni	1000t	1,045	40,000	38	6.01	Russia (24%)	Canada (18%)
Nb	t	23,600	3,500,000	148	6.61	Brazil (89%)	Canada (10%)
Pt	kg	378,000	71,000,000	188	12,180	South Africa (60%)	Russia (31%)
REE	t	82,000	100,000,000	1220		China (85%)	U.S.A. (6%)
Re	kg	46,000	2,500,000	54	750	Chile (32%)	U.S.A. (20%)
Se	t	1,480	70,000	47	5.622	Japan (37%)	Canada (30%)

Si	1000t	3,400	N.A.	N.A.	1.28	China (27%)	Russia (13%)
Ag	t	17,199	280,000	16	170	Mexico (14%)	Peru (13%)
Sr	t	304,000	6,800,000	22	0.07	Mexico (40%)	Spain (31%)
Ta	t	495	19,000	38	74.96	Australia (71%)	Brazil (18%)
Th	t	7,800	1,200,000	154	82.5	India (64%)	Brazil (18%)
Sn	1000t	216	7,700	36	8.06	China (37%)	Indonesia (22%)
Ti	1000t	3,780	327,000	87	9.37	Australia (53%)	Norway (16%)
W	t	31,000	2,000,000	65	47	China (77%)	Russia (11%)
V	t	42,800	10,000,000	234	4.39	China (37%)	South Africa (37%)
Zn	1000t	7,977	190,000	24	1.17	China (19%)	Australia (15%)
Zr	t	941,000	36,000,000	38	20～26	Australia (43%)	South Africa (43%)

*Production figures are based on most recent data(1999).(Asbest, 1994)
N.A.: not available South Africa: Republic of South Africa
(Source: WBMS, Mineral Commodity Summaries, United Nations Energy Statistics etc)

Table 1: Production and reserves of 35 minerals
(Source: WBMS, Mineral Commodity Summaries, United Nations, Energy Statistics, etc.)

The reserves of Ag, Au, As, Sr, Pb, Zn are not sufficient for even 25 years at the current rate of production. Reserve life expectancies of 12 minerals including Cu, Mn, Mo, Cd, Sn, etc., vary from 25 to 50 years. The total world reserves of other resources seem adequate for the next 50 years. As mentioned previously, new discoveries and advances in mining technology have added to the reserves of various mineral commodities. Reserves are not fixed. Additional reserves and cumulative consumption of 16 essential metals over the period 1970-95 are shown in Figure 2. For gold, using 1970 as the index (1970=100) of additional reserve, the 1970-95 increase in reserves is approximately sevenfold, and cumulative consumption has more than tripled. In other words, six times the gold reserves in 1970 were discovered and more than three times the 1970 reserves were consumed during 1970-95. Currently, discoveries and technologies to increase the reserves of many metals are divided in the following three categories.

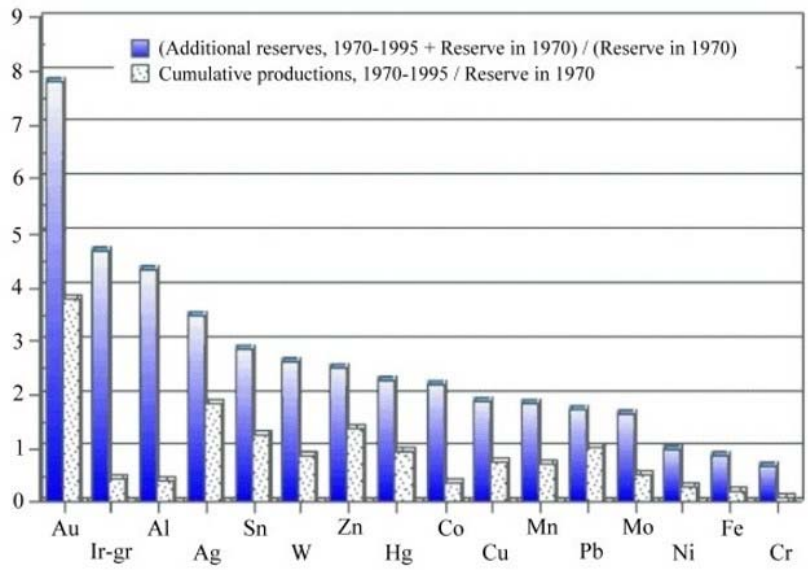

Figure 2: Additional Reserves and Cumulative Production of 16 Essential Metals between 1970-1995. *(Revised from Nishiyama, T. (1995). Resource Depletion Calculated by the Rate of the Reserve Plus Cumulative Consumption to the Crustal Abundance for Gold. Nonrenewable Resources, Vol.4, No.3, p.258.)*

Exploration strategies vary widely, dependent upon the mineral commodity species, the geologic and climatic environment, political and social restrictions, and available resources. Exploration programs focus progressively on decreasing size, from large to narrow research areas using methods increasing in cost per unit area, with a declining risk of failure. The principal programs from reconnaissance surveys into detailed ones include three stages: (1) conventional prospecting consisting of the search for directly observable natural features commonly associated with ore mineralization, or literature and geologic research with the selection of geologically favorable localities;(2) multistage coverage of the area selected involving detailed geologic mapping, geochemical and/or geophysical coverage, and/or the use of special techniques;(3) and finally a drilling program and/or underground exploration by shafts, drifts, and crosscuts.

2. Geologic Prospecting

Geology provides the framework in which mineral exploration and the integrated procedures of remote sensing, geophysics, and geochemistry are planned and interpreted. Mineral resources have been formed by a variety of processes and in various places throughout the 4600 million year history of crustal development. The mineral deposits can, for convenience, be classified into three types based on their formative processes from magmatic to surface genesis, magmatic process, the process of solution-dominated ore genesis, and the transport of particulate matter at the earth's surface.

2.1. Ore Deposits Formed During Magmatic Process

Certain formations of igneous rocks may become concentrated into bodies of sufficient size and richness to constitute valuable mineral deposits such as chromium, platinum and REE. Representatives of magmatic concentration are many and widespread, but the products yielded are not numerous. Chemical and mineralogical evolution is attended by the formation and segregation of two groups associated with ultra-basic and acidic magma.

2.1.1. Separation and Concentration due to Crystallization in Basic Magma at Specific Places and at Specific Stages

The resulting concentrations of these minerals occupy predictable parts of layers of igneous rocks (e.g. platinum, chromite, ilmenite and magnetite deposits). The mineral deposits formed by early magmatic segregation are generally lenticular and of relatively small size. Commonly, they are disconnected pod shaped lenses, stringers, and bunches. Less commonly and more importantly, they form layers in the host rock. The most famous example of this type of deposit is the Bushveld Igneous Complex in South Africa, where stratiform bands of chromite of remarkably uniform thickness lie parallel to the pseudo-stratification of the enclosing mafic igneous rocks and can be traced for several kilometers (Figure 3). Even more remarkable is another thin layer of pyroxenite, the "Merensky Reef" horizon, bounded above and below by thin layers of chromite that contain economic quantities of platinum. Currently this layer has supplied most of the world's demand for platinum

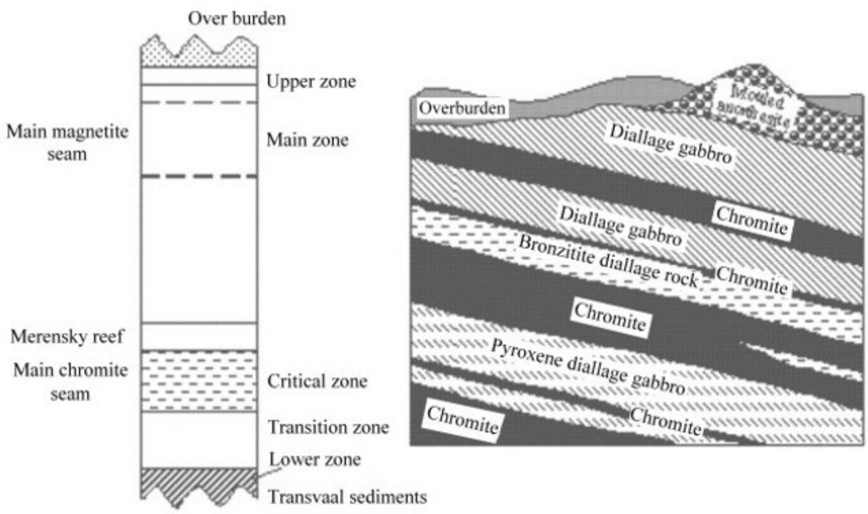

Figure 3: Chromite Deposits and Platinum Deposits (Merensky Reef)
(by Jensen, M.L. and Bateman, A.M. (1979). Economic Mineral Deposits, p.85, John Wiley & Sons, New York.)

2.1.2. Separation and Concentration due to Immiscibility in the Melt

Nickel-copper deposits associated with basic and ultrabasic rocks and REE, niobium-tantalum deposits associated with alkali rocks are well known as typical of this group. Although metallic oxides do not or rarely form immiscible phases in silicate magma, it has been proved that an immiscible sulfide melt, which concentrates copper and nickel, occurs during crystallization. The Sudbury irruptive, which has for a long time been the most important source of nickel, is formed in this manner. Deposits consisting of nickel-copper ores, with accompanying platinum, gold, silver, and other elements are in a stratiform complex composed of the lower norite and the upper micropegmatite (Figure 4).

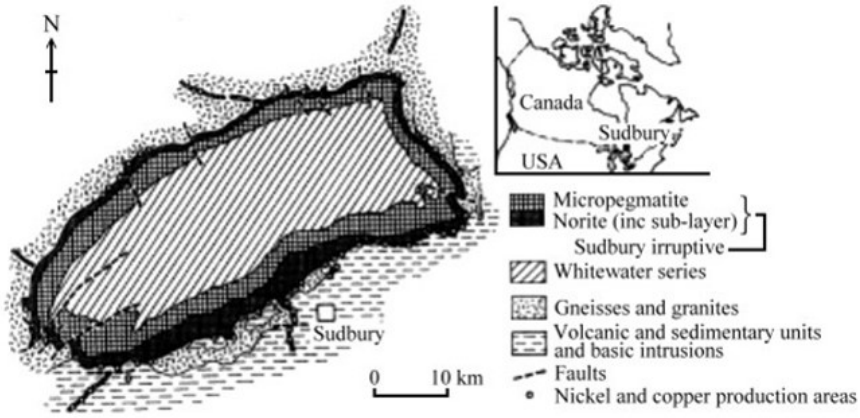

Figure 4: Geological Map of Sudbury Region (After South et al., 1969.)

Carbonatite consisting of alkaline rocks such as nepheline syenite is also an example of immiscible liquid segregation. The carbonatites of economic importance are mostly associated with a source of rare-earth elements, Nb, Ta, U, Th, Zr and Hf etc.

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Biographical Sketches

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