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Opportunities in global mineral resources

Jonathan G. Price

State Geologist Emeritus. Nevada Bureau of Mines and Geology. University of Nevada, Reno.
2175 Raggio Parkway. Reno, Nevada 89512. USA
jprice@unr.edu

ABSTRACT

The trends of increasing mineral production are likely to continue as global population and standards of living rise. Opportunities for exploration and metallurgical research are particularly interesting for certain mineral commodities. With 19% of the global population and a growing economy, China is a leader in the production of many commodities but needs to import many others. India has 17% of the world's population and is an emerging major producer and consumer. Those commodities with high prices relative to their abundance, large markets, and limited production from China (<19% of the global total) are likely to be most attractive. These include gold, platinum-group elements, uranium, lithium, cobalt, niobium, nickel, chromium, titanium, potassium, and iron.

Keywords: China, cobalt, global, lithium, markets, mineral, resources.

Oportunidades en los recursos minerales globales

RESUMEN

Es probable que las tendencias del aumento de la producción de minerales continúen a medida que aumenta la población mundial y los niveles de vida. Las oportunidades para la exploración y la investigación metalúrgica son particularmente interesantes para ciertos productos minerales. Con un 19% de la población mundial y una economía en crecimiento, China es líder en la producción de muchos productos básicos, pero necesita importar muchos otros. Con el 17% de la población, India es un importante productor y consumidor emergente. Aquellos productos con precios altos en relación con su abundancia, grandes mercados y una producción limitada de China (<19% del total mundial) probablemente sean los más atractivos. Estos incluyen oro, elementos del grupo del platino, uranio, litio, cobalto, niobio, titanio, potasio y hierro.

Palabras clave: China, cobalto, global, litio, mercados, mineral, recursos.

Introduction

Which commodities does a country need to sustain or grow its economy? For which commodities is more research needed on models of formation and methods for extraction? For which commodities should a company explore? These questions are addressed by looking at a set of 44 commodities in terms of price, value of global production, major producing countries, and historical trends. What is considered critical for a country depends on its economic and strategic needs. For example, Schultz *et al.* (2017) focused on 20 mineral commodities that are considered critical for the USA, and Gulley *et al.* (2018) identified 11 commodities for which both China and the USA import more than half their needs.

Price as an Incentive

One approach to answering these questions is to look at the value of commodities in terms of their price versus their ease of discovery. To achieve a first approximation, this can be illustrated by comparing elements in terms of their crustal abundances (Fig. 1). As expected, rarer elements tend to be more expensive than abundant elements. For example, aluminum and iron, two of the most abundant elements, are considerably less expensive (in terms of value per unit of mass) than gold or the platinum-group elements.

There is considerable scatter in the log-log plot of Figure 1, with some elements much more expensive than might be expected given their rarity and others

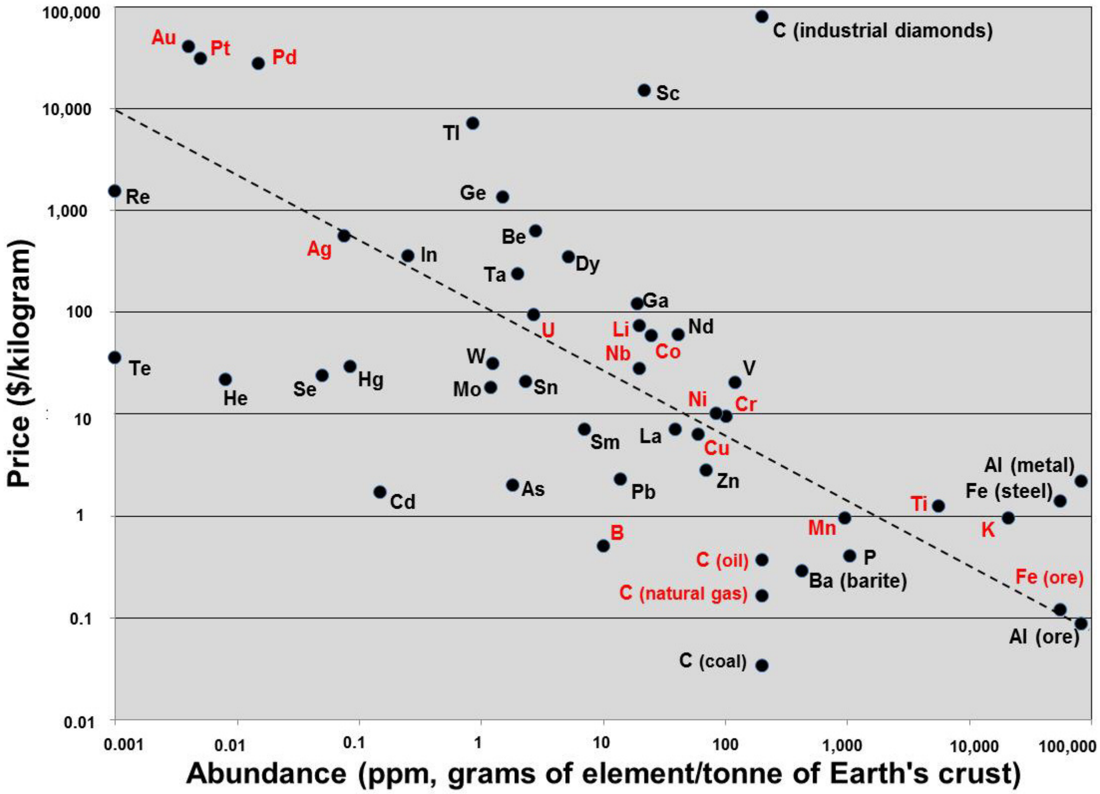

Figure 1. Price versus crustal abundance of selected commodities, updated from Price (2013) and Price and Espi (2014). Highlighted in red are commodities for which the value of annual global production exceeds $1 billion and for which China does not account for more than 19% of global production. Data are from Lide (2015) for abundances; the U.S. Geological Survey (2018) for prices of most commodities; Mineral Prices (2018) for Sc, La, Nd, Sm, Dy, and U prices; Energy Information Administration (2018) for coal, and British Petroleum (2018) for natural gas and oil. The dashed line is arbitrarily drawn to divide commodities with high and low prices relative to their abundance.

Figura 1. *Precio versus abundancia en la corteza terrestre de productos seleccionados, actualizado de Price (2013) y Price and Espi (2014). En rojo se destacan los productos para los cuales el valor de la producción mundial anual supera los mil millones de dólares y para los cuales China no representa más del 19% de la producción mundial. Para abundancias, los datos son de Lide (2015); el US Geological Survey (2018) para los precios de la mayoría de los productos básicos; precios de minerales (2018) para precios de Sc, La, Nd, Sm, Dy y U; Administración de Información de Energía (2018) para el carbón y British Petroleum (2018) para gas natural y petróleo. La línea discontinua se traza arbitrariamente a fin de dividir los productos con precios altos y bajos en relación con su abundancia.*

much less expensive. Some elements that are by-products of others tend to be less expensive, relative to their abundance. These include rhenium (mostly a by-product of production from porphyry copper-molybdenum deposits), tellurium and selenium (by-products of copper-sulfide smelting), cadmium (which geochemically follows zinc), arsenic (byproduct of copper, gold, and lead production), and lower-value rare-earth elements (REE, e.g., lanthanum and samarium, coproducts of higher-value REEs such as neodymium and dysprosium). Helium is relatively inexpensive in part because it is a by-product of natural gas and in part because its price is controlled by government.

Some elements that have reduced use due to toxicity also are relatively less expensive (e.g., mercury, cadmium, arsenic, and lead), although one such element (thallium) is anomalously expensive, probably due to some unique uses in gamma-ray detection, high-temperature superconductors, and infrared optics (Bennett, 2018).

The price of mineral commodities depends in part on the difficulty of processing to produce the purified product. For example, the processing of aluminum ore (mostly aluminum hydroxide) requires electricity to break aluminum-oxygen bonds and produce metallic aluminum; this increases the price 25-fold (from $0.087/kg Al in ore to $2.17/kg metallic Al). Similarly, the reduction of magnetite (Fe_3O_4) and hematite (Fe_2O_3) ores to produce steel requires breaking iron-oxygen bonds, thereby increasing the price of iron by nearly 12-fold (from $0.12/kg Fe in ore to $1.40/kg steel).

Some mineral commodities are relatively inexpensive because they are sold with limited processing that does not require the refinement of pure elements. These include barium (for which the major uses are as barite, the primary ore mineral that is mined), boron (which is processed into boric acid and other products without the energy-intensive breaking of boron-oxygen bonds in its minerals), phosphorus (which is mined as the phosphate mineral apatite and is primarily used in phosphate fertilizer, without making elemental phosphorus), and carbon as coal, natural gas, or oil (Fig. 1).

Interestingly, one of the other forms of carbon, diamond, is much less common than coal and is correspondingly much more expensive. According to Olson (2018), industrial diamonds commanded a price of approximately $15,90/carat ($79,500/kg) in 2017, the highest value among the selected commodities in Figure 1. Even rarer than industrial diamonds are gem-quality diamonds. According to the Antwerp World Diamond Center (2018), depending on clarity and colour, a raw, one carat diamond may cost between $1,045 and $19,190 ($5 million to $19 million/kg). In comparison, the fossil fuels are inexpensive relative to the crustal abundance of carbon and the general trend in Figure 1. Using average prices in 2016, carbon as coal was worth approximately $0.034/kg (Energy Information Administration, 2018), carbon as natural gas was worth approximately $0.16/kg, and carbon as oil was worth approximately $0,37/kg (British Petroleum, 2018).

Examination of Figure 1 suggests that a few commodities that have high prices relative to their crustal abundances may be good targets for exploration and research: gold, platinum-group elements, thallium, germanium, tantalum, beryllium, scandium, gallium, certain REEs, lithium, cobalt, vanadium, titanium, and potassium.

Global Markets

Another factor to consider in deciding which commodities to choose for exploration or research is the global market for the commodities. Table 1 lists the global annual production values of 44 selected commodities. Unless your company has a particularly high-grade and/or large deposit that would be more economically favourable than current resources, you may want to avoid commodities for which global markets are small (with annual values less than $1 billion: As, Be, Cd, Ga, Ge, He, In, industrial diamonds, REE, Re, Sc, Se, Ta, Te, Tl). Unless prices rise substantially, the markets for these commodities may be too small for new producers to gain a significant share. Nonetheless, producers of these commodities, particularly as by-products, may want to optimize production, if the costs of doing so are not prohibitive.

Economic Development in China

China is clearly the global leader in mineral production. Of the 44 mineral commodities highlighted in Table 1, China leads in the production of 21 of them and is one of the top three producers of 28 (Fig. 2, Table 2). Other leaders are South Africa and the United States of America (4 of the 44 mineral commodities); Australia (3); Chile and the Democratic Republic of Congo (2 each); and Russia, Canada, Kazakhstan, Brazil, Mexico, Indonesia, and Turkey (1 each). Given that China has 19% of the world's population, if mineral resources were geologically and geographically more or less evenly distributed or easy to find anywhere, and if standards of living and economies were comparable between countries, one would expect China to produce approximately 19% of each commodity. In contrast, China produces more than 19% of at least 19 of these commodities, including nine for which it accounts for more than half of global production (As, Ge, Pb, Hg, P, REE, Te, W, and V). This is in part due to China's robust economy, which is bolstered by its policies of promoting domestic mineral production, domestic economic development, and international exports. For example, according to statistics compiled by the U.S. Geological Survey (2018), China produces 54% of global refined aluminum and 50% of global steel.

Although helium production figures for China are not available, it is unlikely that China's production exceeds 3.9% of global production, their percentage of global natural gas production, according the British Petroleum (2018). Most helium is produced from natural gas that occurs in sedimentary rocks that overlie granitic basement rocks, from which helium is generated through the decay of uranium and thorium.

China must import many mineral resources to meet its demand (Gulley *et al.,* 2018). In focusing on exploration and research on new resources or improved methods for extraction, some attention should be given to commodities for which China currently does not have enough domestic production to meet its needs (assumed to be ones for which China's percentage of global production is less than 9%): boron, chromium, cobalt, helium, industrial diamonds, lithium, natural gas, nickel, niobium, oil, palladium, platinum, tantalum, and uranium. Of these, metals with annual markets in excess of $10 billion include chromium and nickel as well as platinum-

Commodity	Value (US $)	Major producers
Aluminium (Al)	9.0×10^9	Australia (28) China (23), Guinea (15), Brazil (12), India (9)
Arsenic* (As)	7.0×10^7	China (68), Morocco (21), Namibia (5), Russsia (4), Belgium (3)
Barium (Ba)	1.3×10^9	China (39), India (14), Morocco (13), Iran (6), Kazakhstan (6)
Berylium (Be)	1.4×10^8	USA (74), China (22), Mozambique (3), Brazil (1)
Boron (B)	7.0×10^9	Turkey, USA, Peru, Chile, Kazakhstan, Argentina
Cadmium* (Cd)	3.9×10^7	China (36), Korea (16), Japan (10), Canada (7), Kazakhstan (7)
Coal	2.4×10^{11}	China (45), India (10), USA (9), Australia (7), Indonesia (6)
Chromium (Cr)	2.9×10^{11}	China (4), Kazakhstan (17), India (10), Turkey (9)
Cobalt (Co)	6.5×10^9	DCR-Congo (58), Russia (5), Australia (5), Canada (4), Cuba (4)
Copper (Cu)	1.2×10^{11}	Chile (27), Peru (12), China (9), USA (6), Australia (5), DCR (4)
Gallium* (Ga)	3.8×10^7	China, Japan, Korea, Russia, Ukraine
Germanium *(Ge)	1.8×10^8	China (>50), Russia, USA
Gold (Au)	1.3×10^{11}	China (14), Australia (10), Russia (8), USA (7), Canada (6), Peru (5)
Helium (He)	5.1×10^8	USA (48), Qatar (34), Algeria (11) Australia (3), Russia (2)
Indium* (In)	2.6×10^8	China (43), Korea (30), Japan (10), Canada (10), France (3)
Industrial diamonds	9.9×10^8	DRC (31), Russia (29), Australia (23), Botswana (10), S. Africa (3)
Iron (Fe)	1.8×10^{11}	Australia (369, Brazil (29), China (14), India (8), Russia (4)
Lead (Pb)	1.1×10^{10}	China (51), Australia (10), USA (7), Peru (6), Russia (5), Mexico (5)
Lithium (Li)	3.2×10^9	Australia (43), Chile (32), Argentina (13), China (7), Zimbawe (2)
Manganese (Mn)	1.5×10^{10}	South Africa (33), China (16), Australia (14), Gabon (10), Brazil (8)
Mercury (Hg)	7.3×10^7	China (80), Mexico (12), Kyrgyzstan (2), Peru (2), Tajikistan (1)
Molybdenum (Mo)	5.2×10^9	China (45), Chile (20), USA (15), Peru (9), Mexico (4), Armenia (2)
Natural gas	$3{,}1 \times 10^{11}$	USA (21), Russia (16), Iran, Qatar (5), Canada (4), China (4)
Nickel (Ni)	2.1×10^{10}	Indonesia (19), Philippines (11), Canada (10), New Caledonia (10)
Niobium (Nb)	3.1×10^9	Brazil (98), Canada (9)
Oil	3.1×10^{12}	USA (13), Saudi Arabia (13), Russia (12), Iran (5), Canada (5), Iraq (5)
Palladium (Pd)	5.8×10^9	Russia (39), South Africa (37), Canada (9), USA (6), Zimbabwe (6)
Phosphorus (P)	2.0×10^{10}	China (53), USA (11), Marocco (10), Russia (5), Jordan (10), Brazil (10)
Platinum (Pt)	6.2×10^9	South Africa (70), Russia (11), Zimbabwe (6)
Potassium (K)	3.3×10^{10}	Canada (29), Russia (17), Belarus (15), China (15), Germany (7)
Rare earths (REE)	6.7×10^8	China (81), Australia (15), Russia (2), Brazil (2), Thailand (1), India (1)
Rhenium (Re)	8.0×10^7	Chile (52), Poland (17), USA (16), China (6), Kazakstan (2)
Scandium (Sc)	3.1×10^{11}	China, Kazakstan, Russia, Ukraine
Selenium* (Se)	7.1×10^7	China (28), Japan (23), Germany (22), Belgium (6), Canada (5)
Silver (Ag)	1.4×10^{10}	Mexico (22), Peru (18), China (10), Russia (6), Poland (6)
Tantalum (Ta)	1.2×10^8	Rwanda (30), DCR (28), Nigeria (15), Brazil (8), China (7)
Tellurium* (Te)	1.8×10^7	China (67), Sweden (10), Russia (8), Canada (5), Bulgaria (1)
Thallium* (Tl)	6.5×10^7	China, Kazakstan, Russia
Tin (Sn)	6.1×10^9	China (34), Indonesia (17), Burma (17), Brazil (9), Bolivia (6), Peru (6)
Titanium (Ti)	5.3×10^9	South Africa (19), Australia (19), China (11), Mozambique (8)
Tungsten (W)	2.9×10^9	China (83), Vietnam (8), Russia (3), Bolivia (1), UK (1), Austria (1)
Uranium (U)	6.2×10^9	Kazakstan (39), Canada (23) Australia (10), Niger (6), Namibia (6)
Vanadium (V)	1.6×10^9	China (54), Russia (20), South Africa (16), Brazil (11)
Zinc (Zn)	3.7×10^{10}	China (39), Peru (11), India (10), Australia (10), USA (6), Mexico (5)

Table 1. Major producers of 44 selected mineral commodities (with percentage of world total production in parentheses, where known). Data are for 2017 from the U.S. Geological Survey (2018) for all commodities except coal (International Energy Agency, 2018, and Energy Information Administration, 2018), oil and natural gas (British Petroleum, 2018), and uranium (World Nuclear Association, 2018), for which data are for 2016. Value is annual production times average price. Commodities noted with an asterisk (*) are produced or refined in these countries but not necessarily mined there.

Tabla 1. *Principales productores de 44 productos minerales seleccionados (con el porcentaje de la producción total mundial entre paréntesis, cuando se conoce). Los datos corresponden a 2017 del Servicio Geológico de EE. UU. (2018) para todos los productos, excepto el carbón (Agencia Internacional de Energía, 2018 y la Administración de Información de Energía, 2018), el petróleo y el gas natural (British Petroleum, 2018) y el uranio (Asociación Nuclear Mundial, 2018), cuyos datos corresponden a 2016. El valor es la producción anual multiplicada por el precio medio. Los productos que se indican con un asterisco (*) se producen o refinan en estos países, pero no necesariamente se extraen allí.*

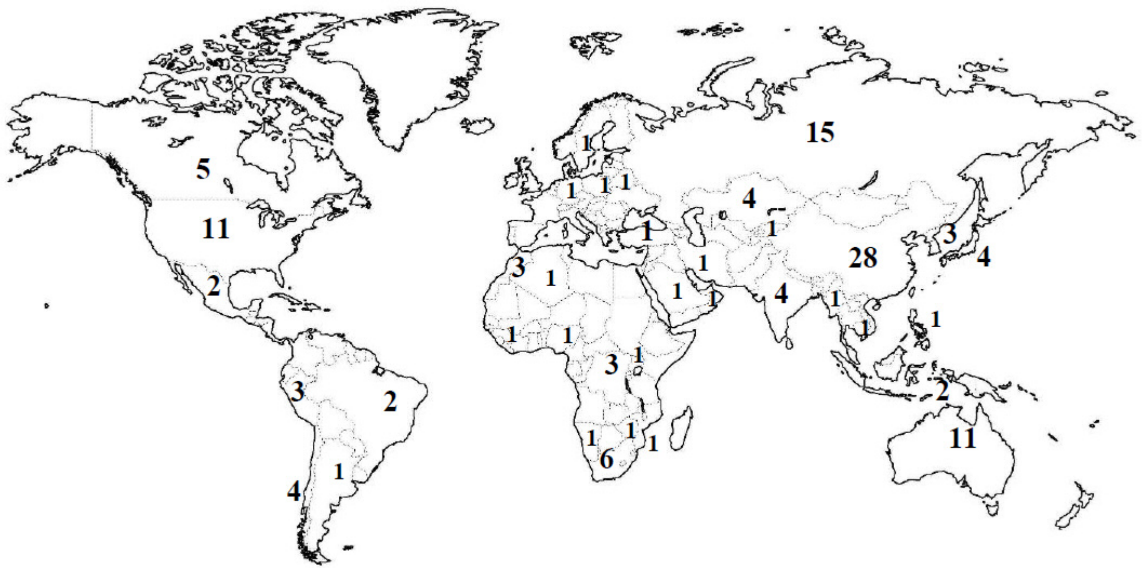

Figure 2. Number of selected mineral commodities (among the 44 listed in Table 1) for which these countries are among the top three global producers. See Tables 1 and 2 for details.
Figura 2. *Número de productos minerales seleccionados (entre los 44 enumerados en la Tabla 1) para los cuales estos países se encuentran entre los tres principales productores mundiales. Consulte las Tablas 1 y 2 para más detalles.*

group elements (combining the values of palladium and platinum). Interestingly, these are mineral resources commonly associated with mafic and ultramafic igneous rocks that occur in Precambrian cratons.

Lithium and cobalt as examples

As the demand has risen for rechargeable lithium-ion batteries (used in electrical cars, electrical storage, and consumer electronics), the price of lithium doubled from 2015 to 2017 (Jaskula, 2018). Facada (2018) reported a price of $23,093 to $23,890/tonne Li_2CO_3 on 13 April 2018, approximately 3.6 times the average price in 2015 (Jaskula, 2018). In 2017 global lithium production, dominated by Australia, Chile, and Argentina, had a value of $3.2 billion (Table 1).

Bradley *et al.* (2017) summarized the global resources of lithium and its geological occurrences. Significant resources exist in deposits that have been mined commercially: closed-basin brines (with current production from Chile, Argentina, and USA) and pegmatites (with current production from Australia and Brazil). Other known resources include lithium-rich granites, oilfield brines, lithium clays, and lithium zeolites. The lithium clays are particularly interesting, as some appear to be more easily treated metallurgically, depending on where the lithium occurs in the crystal structure of hectorite (smectite-group mineral), tainiolite (mica or illite), illite-smectite mixtures, or other clay minerals (Morisette, 2012; Stillings and Morisette, 2012; and Price *et al.,* 2018). There are sufficient resources to meet expected demand, but more research is needed, particularly on processes to extract lithium from brines without time-consuming evaporation and on processes to extract lithium from different clays.

Cobalt, which is also used in rechargeable lithium-ion batteries, has seen a dramatic increase in price in recent years, nearly doubling from 2015 to 2017 (Shedd, 2018) and continuing to rise; the London Metal Exchange (2018) indicated a price in April 2018 three times higher than the average price in 2015. Over half of global production comes from the Democratic Republic of Congo (DRC), mostly as a by-product of copper production (Table 1). In 2017 global cobalt production had a value of $6.5 billion. China has invested in mining in DRC to guarantee supplies for its industries (Shedd *et al.,* 2017).

Slack *et al.* (2017) noted that there are significant resources of cobalt associated with sediment-hosted copper-cobalt deposits (as in DRC) as well as by-products of ores associated with mafic and ultramafic igneous rocks: magmatic nickel-copper sulfide deposits and nickel laterites. Schulz *et al.* (2017) also tabulated significant cobalt resources associated with black-shale hosted nickel-copper deposits, iron-copper skarns, iron-oxide-copper-gold deposits, volcanogenic massive sulphide deposits of copper, poly-

Country	Percentage of World		Mineral commodities among the top three producing countries
	Pop.	Land	
China*	19	6.4	Al, As, Ba, Be, Cd, coal, Cu, Ga, Ge, Au, In, Fe, Pb, Mn, Hg, Mo, P, REE, Sc, Se, Ag, Te, Tl, Sn, Ti, W, V, Zn
India*	17	2.2	Ba, coal, Cr, Zn
USA*	4.4	6.5	Be, B, coal, Ge, He, Pb, Mo, natural gas, oil, P, Re
Indonesia*	3.5	1.3	Ni, Sn
Brazil*	2.8	5.7	Fe, Nb
Pakistan	2.8	0.5	
Nigeria	2.6	0.6	Ta
Bangladesh	2.1	0.1	
Russia*	1.9	11.4	industrial diamonds, Co, Ge, Au, nat. gas, oil, Pd, Pt, K, REE, Sc, Te, Tl, W, V
Japan	1.7	0.3	Cd, Ga, In, Se
Mexico*	1.7	1.3	Hg, Ag
Ethiopia	1.4	0.7	
Philippines	1.4	0.2	Ni
Egypt	1.3	0.7	
Vietnam	1.3	0.2	W
DRC*	1.1	1.6	industrial diamonds, Co, Ta
Iran*	1.1	1.1	natural gas
Turkey	1.1	0.5	B
Germany	1.1	0.3	Se
Burma	0.7	0.4	Sn
South Africa	0.7	0.8	Cr, Mn, Pd, Pt, Ti, V
Korea, South	0.7	0.1	Cd, Ga, In
Spain	0.7	0.3	
Argentina*	0.6	1.8	Li
Algeria*	0.6	1.6	He
Poland	0.5	0.2	Re
Canada*	0.5	6.6	Ni, Nb, Pd, K, U
Morocco	0.5	0.3	As, Ba, P
Peru	0.4	0.9	B, Ag, Zn
Saudi Arabia*	0.4	1.4	oil
Mozambique	0.4	0.5	Be
Australia*	0.3	5.1	Al, industrial diamonds, Co, Au, Fe, Pb, Li, Mn, REE, Ti, U
Kazakhstan*	0.3	1.8	Cr, Sc, Tl, U
Chile	0.2	0.5	Cu, Li, Mo, Re
Zimbabwe	0.2	0.3	Pt
Guinea	0.2	0.2	Al
Rwanda	0.2	0.02	Ta
Sweden	0.1	0.3	Te
Belarus	0.1	0.1	K
Kyrgyzstan	0.08	0.1	Hg
Namibia	0.03	0.5	As
Qatar	0.03	0.01	He

Table 2. Percentage of world population of major mineral-producing (among top three of selected commodities) and other populous and large countries. Data are from the U.S. Geological Survey (2018), International Energy Agency (2018), World Nuclear Association (2018), British Petroleum (2018) for commodities and Central Intelligence Agency (2018) for population, with estimates as of July 2017). The largest countries by area are highlighted with an asterisk (*).

Tabla 2. Porcentaje de la población mundial de los principales productores de minerales (entre los tres principales productos seleccionados), además de otros países grandes y poblados. Los datos proceden del Servicio Geológico de EE. UU. (2018), la Agencia Internacional de Energía (2018), la Asociación Nuclear Mundial (2018), el British Petroleum (2018) para productos y la Agencia Central de Inteligencia (2018) para la población, con estimaciones a julio de 2017). Los países más grandes por su extensión se resaltan con un asterisco (*).

metallic veins, and metasedimentary rock-hosted copper-gold deposits. Research on the origins of these deposits, including the hydrothermal geochemistry of nickel, cobalt, and copper, may point to new exploration targets in regions with mafic and ultramafic source rocks. Slack *et al.* (2017) highlighted the need for research on improving metallurgical recovery of cobalt from nickel laterites and on the possible recovery of cobalt from silicates in ultramafic rocks.

The largest cobalt resources, however, are below the oceans. Slack *et al.* (2017) noted that seafloor iron-manganese nodules and seafloor iron-manganese crusts contain more cobalt than all the other known resources combined, but development of these resources faces legal hurdles and technological difficulties that may be overcome through research and development. An interesting incentive for exploration and research on the seafloor resources is the attractiveness of nickel and perhaps iron, two other commodities that are favourable from the standpoint of their price (Fig. 1), market ($21 billion for Ni, $160 billion for Fe in 2017), and demand from China, which in 2017 accounted for only 5% of global nickel production (McRae, 2018) and 14% of global iron-ore production, as measured by iron content (Tuck, 2018).

Optimism

As global population continues to rise, so has the standard of living for many people. A measure of average standard of living is per capita consumption (defined as production divided by population). Copper and gold illustrate the global rise in production and per capita consumption (Figs. 3 & 4). Copper is a metal with a wide range of industrial applications, and average per capita consumption of copper can be viewed as a measure of global industrialization. While global population has risen by a factor of 4.5 from 1900 to 2017, copper production has increased by a factor of 40, and average per capita consumption has increased by a factor of 8.9 (Fig. 3). Gold can be viewed largely as money, and average per capita consumption of gold can be viewed largely as a measure of global wealth. Gold production has risen by a factor of 8.2 from 1900 to 2017, and average per capita consumption has risen by a factor of 1.8 (Fig. 4).

China has experienced strong economic growth in recent decades, and India is developing economically at a somewhat lesser pace. Steel production can be viewed as a measure of economic development. China has seen a dramatic increase in its steel pro-

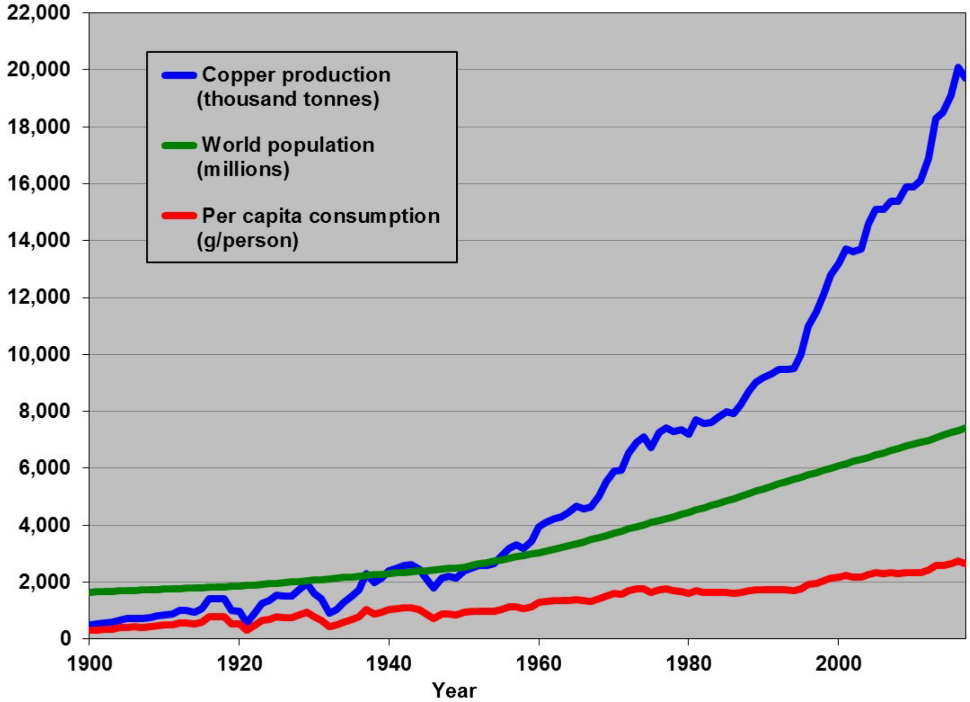

Figure 3. Annual global copper production, 1900-2017 (production data from U.S. Geological Survey and U.S. Bureau of Mines; population data from U.S. Central Intelligence Agency), updated from Price (2013) and Price and Espi (2014).

Figura 3. *Producción anual de cobre, 1900-2017 (datos de producción del U.S. Geological Survey y U.S. Bureau of Mines; datos de población de U.S. Central Intelligence Agency), actualizados de Price (2013) y Price and Espi (2014).*

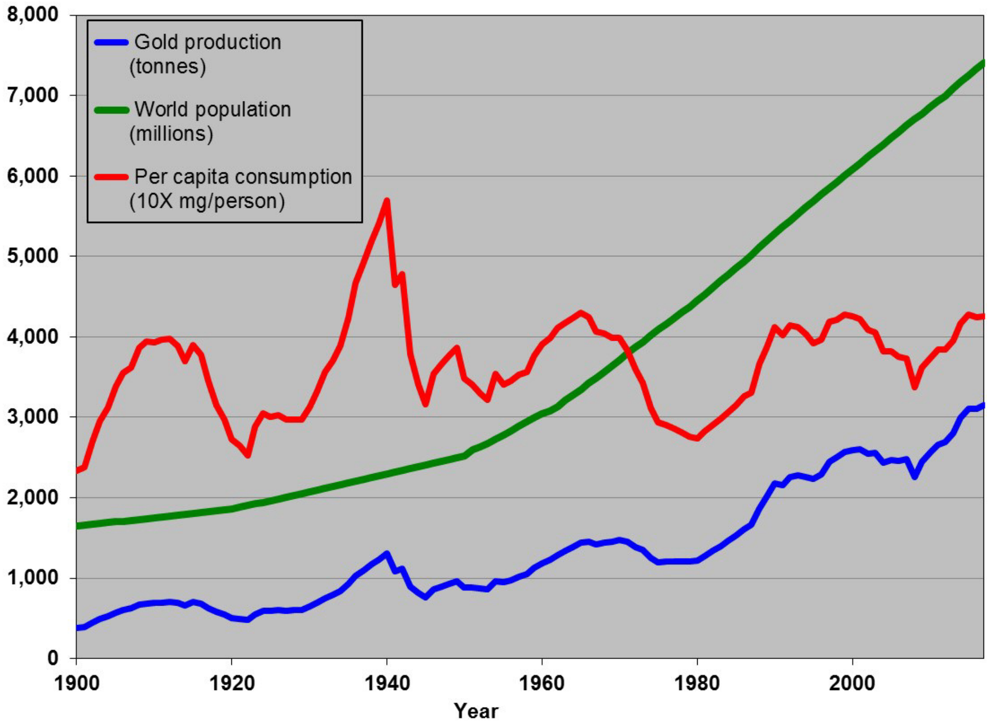

Figure 4. Annual global gold production, 1900-2017 (production data from U.S. Geological Survey and U.S. Bureau of Mines; population data from U.S. Central Intelligence Agency), updated from Price (2013) and Price and Espi (2014).
Figura 4. *Producción mundial anual de oro, 1900-2017 (datos de producción del U.S. Geological Survey y U.S. Bureau of Mines; datos de población de U.S. Central Intelligence Agency), actualizados de Price (2013) y Price and Espi (2014).*

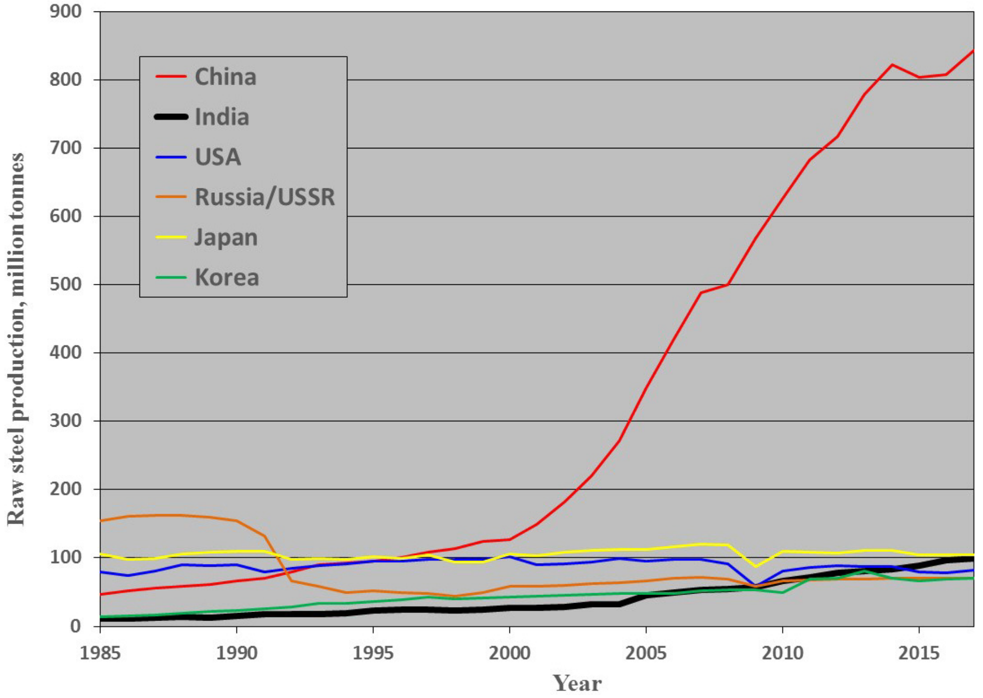

Figure 5. Annual raw steel production of major producing countries, 1985-2017 (data from U.S. Geological Survey and U.S. Bureau of Mines); data for Russia start at 1992, data for USSR end in 1991.
Figura 5. *Producción anual de acero en bruto de los principales países productores, 1985-2017 (datos del U.S. Geological Survey y U.S. Bureau of Mines); los datos para Rusia comienzan en 1992, los datos para URSS finalizan en 1991.*

duction in the last two decades, by a factor of 7.8 from 1997 to 2017 (Fig. 5). During the same period, India's steel production increased by a factor of 4.2, while that of other major producers (Japan, USA, Russia, and Korea) had minimal changes.

The trends of increasing mineral production are likely to continue as global population and standards of living rise. Recycling has become increasingly important for several commodities, but newly mined resources will be needed for the foreseeable future. Successful exploration for large and/or high-grade deposits of all commodities likely will be worthwhile, and metallurgical research on improving extraction of elements as by-products from ores and as primary products from new types of deposits will help meet demands. Those elements with high prices relative to their abundance, large markets, and limited production (<19% of the global total) from China are likely to be most attractive. These include gold, platinum-group elements, uranium, lithium, cobalt, niobium, nickel, chromium, titanium, potassium, and iron.

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