# Chapter 3
# Rare and Strategic Metals

**Yves Fouquet and Bruno Martel-Jantin**

## Context

In western countries, an increasing share of metals is imported. While the supply of metals used in everyday products requires to be reduced, many economic sectors could be considerably affected. A distinction should be made between base metals (iron, copper, zinc, lead…) and rare metals, little known to the general public, and yet at the heart of high technology industries.

Over the past few years, the rare metals market has been driven by China's and India's second industrialisation phase, and the development of their high technology industry. The information and new energies era creates demand for an increasingly wide range of metals, in particular: tantalum in mobile phones; indium in liquid crystal displays; gallium, cadmium, indium and selenium in new generation, high yield photovoltaic cells. These metals, of which the volumes traded are very low, are highly sensitive to temporary imbalances between supply and demand. The uses of rare metals evolve rapidly according to technological innovations and these metals can become strategic. They cannot be considered independently of the base metals with which they are generally associated in deposits (Fig. 3.1).

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Y. Fouquet (✉)
Géosciences marines, Centre Bretagne, Ifremer,
BP 70, 29280 Plouzané, France
e-mail: yves.fouquet@ifremer.fr

B. Martel-Jantin
Bureau de recherches géologiques et minières (BRGM),
39–43, quai André Citroën, 75015, Paris, France
e-mail: bruno.martel.jantin@brgm.fr

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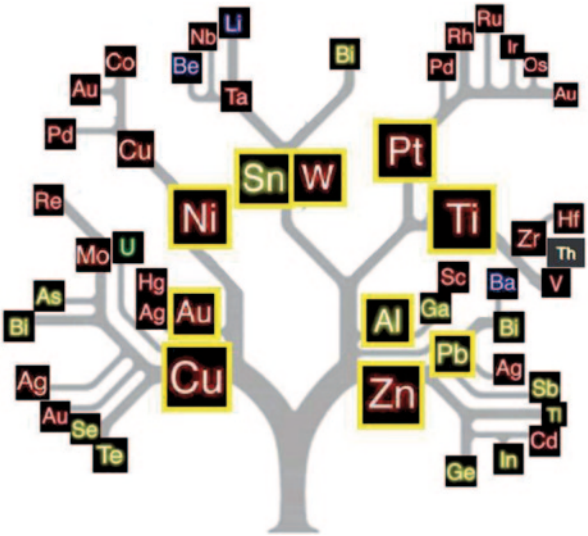

**Fig. 3.1** Base metals and associated rare metals

### Example of rare earth elements

Rare earth metals are a group of metals with similar properties and are comprised of scandium (Sc), yttrium (Y) and the 15 lanthanides. Despite their name, they are not rare: rare earth metals are found in the Earth's crust in larger quantities than copper or lead, at a concentration of around 0.08 %. The relative concentrations of the various lanthanides in these ores can vary from 50 % to a few percent. In terms of applications, the specificity of rare earth elements lies in their particular electronic structure which induces unique chemical, structural and physical properties, put to use in metallurgy, catalysis, glass-making, optics, ceramics, luminescence, magnetics, electronics and green technologies (wind turbines, photovoltaic cells, electric vehicles and energy-efficient lighting). One of the current major challenges concerns the manufacture of high strength magnets for electric motors. Their close chemical properties can sometimes make them difficult to distinguish.

China's monopoly in this field is very alarming. The United States, like other countries, including the European Union which published a report on this subject in June 2010, are concerned about the risk of China stopping exports, as the country possesses 97 % of world production of rare earth element ores and 37 % of known reserves. The United States and Australia have significant reserves (15 % and 5 % respectively), but have ceased to exploit them due to China's highly competitive prices and to environmental concerns. This preponderance alarms western countries which are seeking to diversify their supply, especially as China declared that it hopes to reduce its export quotas to 35,000 t per annum (out of a total production of 110,000 t) from

2010. The reasoning behind this decision is based on the desire to preserve rare resources and the environment. Chinese mineral ores contain a total of a few percent of rare earth oxides. This context further supports the need to diversify supply. Rare earth extraction and processing prove to be very costly and it may take two to ten years to open up new mines.

Several reasons point towards a restriction in the supply of rare metals: exhaustion of natural minerals; difficulty and/or cost of extraction and processing; dependence due to the limited number of mines and their location; increase in demand due to new technologies.

The pivotal question is whether the necessary mineral resources will be available in time and at an acceptable cost to meet the demand of both developed and emerging countries. With this as a backdrop, the notion of "critical metals" began to emerge a few years ago. A mineral is critical if it is both greatly used and subject to strong potential for supply restriction. Based on these criteria, the data, information and research required to attenuate potential restrictions in supplies of such a mineral can be determined. Criticality also depends on the degree of difficulty in rapidly finding substitutes.

For instance, platinum group metals and rare earths are fundamental for catalytic converters in the automotive industry. To date, no viable replacement product exists for these metals. Similarly, in response to an increase in demand for indium, used in the manufacture of flat screens, the price per kilo of indium rose from around US $ 100 in 2003 to US $ 980 in 2006.

Within this context, it is important to have good knowledge of data on the availability of these metals and to conduct research to fully understand natural concentration processes.

## Factors Affecting Mineral Availability

In the medium and long term (over ten years), availability is related to five factors: geological (does the resource exist?), technical (can the ore be extracted and processed?), environmental and social (can metals be produced in an ecologically and socially acceptable manner?), political (how can governments influence availability through their actions?) and economic (can metals be produced at a cost that users are prepared to pay?).

Many existing and emerging technologies require minerals which are not available in western countries. Dependence on imports can expose a range of industries to political and economic risks. To maintain economic growth, it is important to be familiar with deposit types on a global scale, as well as the restriction potential and the solutions to remedy this situation. In the short and medium term, major restrictions in supply can occur, leading either to the unavailability of the mineral or a rise in prices.

The risks are as follows: major unexpected rise in demand for fully exploited minerals; small markets making it difficult to rapidly increase production to meet demand; production concentrated on a small number of mines, companies or producing countries; minerals extracted as by-products and whose availability is largely determined by the availability of the main product (e.g. gallium as a by-product of bauxite extraction); markets for which there is no significant recycling.

## Critical Metals in the United States

The National Academies report on Minerals, Critical Minerals, and the U.S. Economy published in 2007 applies a criticality matrix to eleven metals: copper, gallium, indium, lithium, manganese, niobium, tantalum, titanium, vanadium, platinum group metals and rare earths. This list is of course liable to evolve over time. Of these eleven minerals, platinum group metals, rare earths, indium, manganese and niobium were considered to be the most critical due to their applications, the difficulty in finding substitutes and the risk for their supply. Although important applications exist for the other minerals (copper, gallium, lithium, tantalum, titanium and vanadium), they were identified as less critical, either because they had ready substitutes, or because the reserves were not potentially subject to restrictions at the time.

In order to identify and increase critical metal resources, the committee recommends improving information and analysis relating to minerals (in particular those that are or may become critical), collecting, disseminating and analysing data, funding activities, including basic sciences and research on essential minerals, in order to improve understanding of global availability and use of minerals.

More recently (December 2010), a specific criticality study on metals related to energy was conducted by the US Department of Energy (Fig. 3.2). It highlights the criticality of metals in the short term (0–5 years) and medium term (5–15 years) for energy needs and in particular renewable energies.

## Critical Metals in Europe

The European Commission’s Raw Materials Initiative (COM 2008, p. 699) highlights the risks for Europe’s supply and competitiveness related to critical metals, while emphasising that these metals cannot be considered independently of the base metals with which they are generally associated in deposits. The EC document recommends an improvement in basic knowledge on geological potential, metal deposits and their exploration in Europe, as well as the development of more efficient extraction technologies, compatible with the maintenance of a sustainable environment and better use of mineral resources. A group is currently working to support the Commission on the possibility of a large-scale European exploration programme. In 2010, the Report of the Ad-Hoc Working Group on Defining Critical

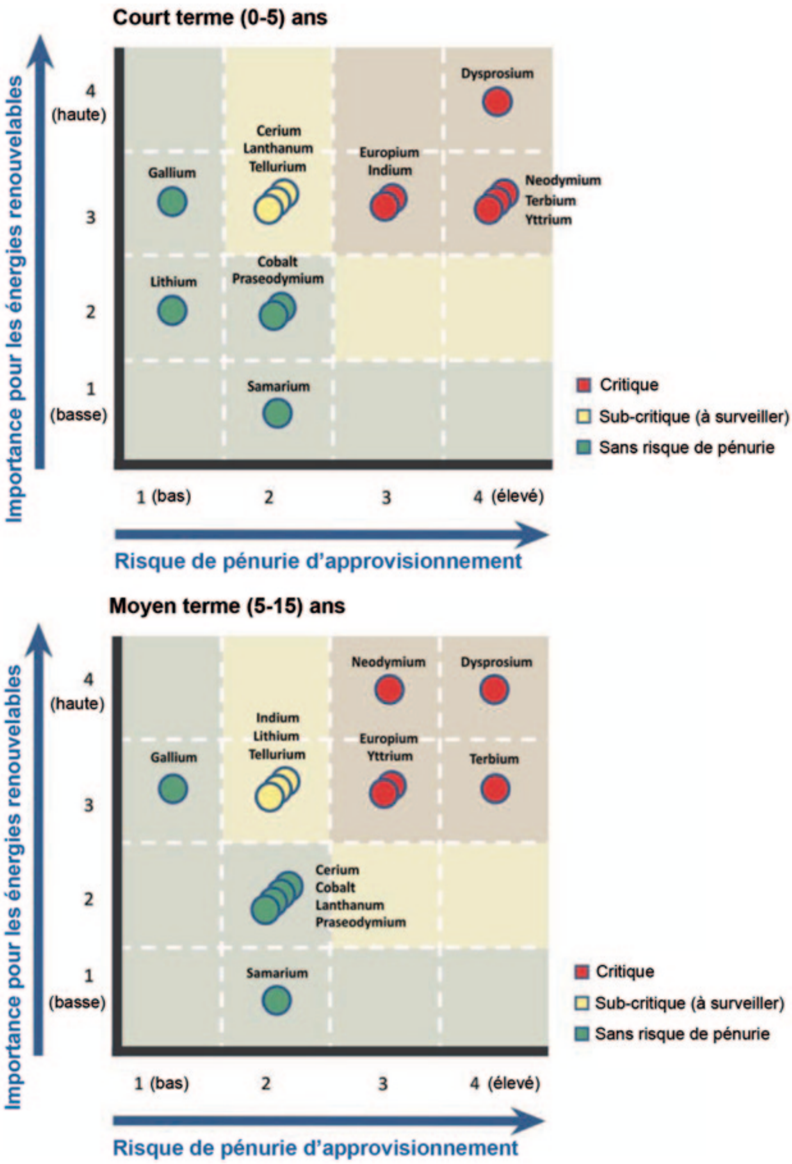

**Fig. 3.2** Criticality matrix designed by the US Department of Energy for metals related to energy, with a short and medium term vision. (Source: US Department of Energy)

Raw Materials, entitled Critical Raw Materials for the EU, specified the degree of criticality of metals and certain materials, based on their economic importance and the risks of supply shortage. This resulted in a list of elements similar to the list established by the United States, in particular for elements such as platinum, rare earths, indium, tantalum and niobium.

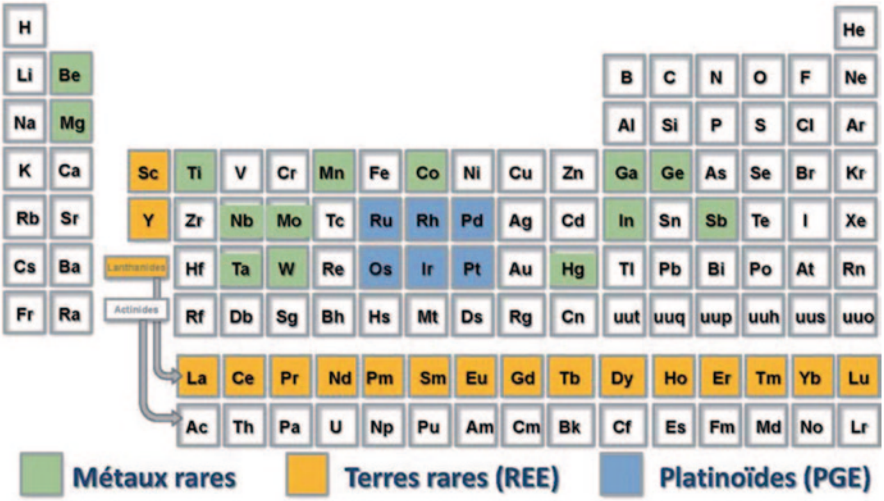

**Fig. 3.3** Critical metals selected by the European Commission

In 2010, Europe drew up a list of critical metals (Fig. 3.3). The European report on critical metals considers that geological scarcity is not a criterion for determining criticality; in the same way, global reserves are not reliable indicators of long term availability. More relevant criteria concern the geopolitical and economic frameworks that affect supply and demand. Thus, growing demand for raw materials is driven by developing countries and new technologies.

Furthermore, several emerging economies, including China, tend to reserve their resources for their own exclusive use. This situation may be aggravated by a concentration of production in only a few countries. The European report considers that raw materials are “critical” when there are risks of supply shortage and when their impact on the economy is higher than that of other raw materials. Two types of risks are considered: firstly the supply risk, taking into account the political and economic stability of the producing countries, the level of concentration of production, the substitution potential and the recycling rate; secondly, the environmental risk, taking into account the impact that strict environmental measures taken by traditionally lax countries in this field would have on supply. On the basis of these criteria, fourteen elements are considered as critical, as they are of high economic importance coupled with a high availability risk.

Discussions are regularly held (Trans-Atlantic Workshop on Rare Earth Elements and Other Critical Materials for a Clean Energy Future, December 2010) between the European Union and the United State to increase collaboration in this crucially important field of mineral raw materials and in particular rare earths, vital for green technologies such as electric car batteries and wind turbines. Efforts are focused on ensuring better information sharing, improving mineral supply security and implementing a more unified approach to this challenge by the European Union and United States.

## Critical Metals in France

In France, a list of strategic metals has been established by the relevant ministries (cf. Table 3.1). This list reveals France's heavy dependence for most rare metals. A list of land-based mines for rare metals should be drawn up, specifying the contents of these elements in order to determine the concentrations to be sought in other regions or other types of deposits and to improve supply security. There is currently no such list which can be used to rapidly assess the value of new indices on a given type of rare metal.

At the Ministry of Research and Higher Education, this question is mainly being addressed within the "Alliance" of institutes concerned by this field, known as ANCRE, which also deals with energy issues.

In the field of energy, the challenges are centered around rare and often critical metals. These metals are used in nuclear energy, batteries, renewable energies, as well as in energy saving processes, the development of new catalysts and chemical hydrogen storage. The challenges in the field of energy concern rhenium, selenium, tellurium, rare earths, uranium and vanadium. Seven major sectors of application have been identified, in which rare metals are or will be critical: nuclear with uranium; batteries with lithium, cobalt and rare earths; renewable energies and energy savings (in particular magnets for generators and electric motors) with rare earths, as well as photovoltaic with silver, cadmium, tellurium, indium, gallium and selenium; non-incandescent lighting with gallium; catalysts with platinum group metals and possibly chemical hydrogen storage with boron; high-temperature superconductivity with rare earths; fuel savings by improving engine performance and using lighter structures with nickel-rhenium for aeronautics and niobium for the automotive industry.

The ANCRE programme highlights the need for a full-fledged research programme to discover new mineral resources in continental masses and in the ocean, to exploit low concentrations or unconventional deposits, to determine their industrial value, to contribute to the evaluation or re-evaluation of land-based and sea-based mineral resources in French territories, their EEZ and partners' economic areas, and to develop efficient and sustainable exploration, exploitation and rehabilitation technologies.

The ANCRE programme proposes two fundamental avenues. The first consists in an inventory of critical metal resources through exploration and knowledge of the national territory, its EEZ and international partners' EEZs, in particular for lithium and rare earths. The second resides in the understanding of the concentration processes of so-called 'small metals'. The proposed research programme aims to develop knowledge of concentration processes for primary (lithium, rare earths) and secondary (by-products) elements in endogenous deposits of Zn, Ni, Cu and bauxites and argillites. Small metals are often by-products of base metals. They help to promote base metals considerably, in a context in which, as their concentration is gradually falling, their exploitation cost is on the rise.

Knowledge of small metal concentration processes is a considerable asset for the exploration, exploitation and strategic choice of base metal deposits, and is worth

**Table 3.1** Concentrations of major and trace metals in the three main types of ocean deposits (Source: BRGM/Ifremer)

| | | Minimum and maximum concentrations | | | |
|---|---|---|---|---|---|
| | | Nodules | Crusts | | Sulphides |
| *Major elements* | | | | | |
| Zinc | ppm | 512–1400 | 532–654 | % | 0.06–37 |
| Copper | ppm | 292–10200 | 729–11079 | % | 0–23 |
| Iron | % | 7–23 | 13–19 | % | 0.7–43 |
| Sulphur | % | 0.1–0.3 | ? | % | 0–47 |
| Manganese | % | 7–26 | 13–23 | % | 0–3 |
| Barium | ppm | 1190–4185 | 1218–1257 | % | 0–34 |
| Silicon | % | 3–11 | 2–4 | % | 0.1–33 |
| Titanium | % | 0.5–1.3 | 0.8–1.3 | % | ? |
| Lead | ppm | 450–1957 | 722–1721 | ppm | 30–142700 |
| Phosphorus | % | 0.1–1.8 | 0.4–2.4 | % | ? |
| *Minor elements* | | | | | |
| Nickel | ppm | 2600–12800 | 2317–4389 | ppm | 1–915 |
| Cerium | ppm | 1–1684 | 547–752 | ppm | ? |
| Yttrium | ppm | 131–267 | 193–218 | ppm | ? |
| Vanadium | ppm | 470–865 | 495–682 | ppm | ? |
| Zirconium | ppm | 70–802 | 397–630 | ppm | ? |
| Cadmium | ppm | 3–12 | <15 | ppm | 3–950 |
| Germanium | ppm | ? | ? | ppm | 1–226 |
| Silver | ppm | 0–1 | <10 | ppm | 3–2100 |
| Arsenic | ppm | 158–1141 | 206–300 | ppm | 11–30000 |
| Indium | ppm | <0.5 | <7 | ppm | 1–204 |
| Antimony | ppm | 24–63 | 58–59 | ppm | 1–1005 |
| Molybdenum | ppm | 238–737 | 238–395 | ppm | 1–399 |
| Cobalt | ppm | 2400–8054 | 4326–11370 | ppm | 1–4931 |
| Thallium | ppm | 12–189 | 124–167 | ppm | (2–43)? |
| Tellurium | ppm | 3–216 | ? | ppm | (0–4)? |
| Selenium | ppm | 0–52 | <15 | ppm | 1–505 |
| Tin | ppm | ? | ? | ppm | 0–216 |
| Mercury | ppm | 0–360 | ? | ppm | 2–274 |
| Gold | ppm | ? | ? | ppm | 0.05–20 |
| *Trace elements* | | | | | |
| Chromium | ppm | 9–180 | 12–26 | ppm | ? |
| Lithium | ppm | 2–160 | ? | ppm | ? |
| Beryllium | ppm | 3–8 | ? | ppm | ? |
| Boron | ppm | 14–273 | ? | ppm | ? |
| Scandium | ppm | 5–19 | 7–14 | ppm | ? |
| Bismuth | ppm | 6–53 | 12 | ppm | 0–63 |
| Bromine | ppm | 0–52 | ? | ppm | ? |
| Hafnium | ppm | 5–54 | ? | ppm | ? |
| Tungsten | ppm | 15–150 | 15–15 | ppm | ? |
| Uranium | ppm | 7–16 | 9–12 | ppm | 0–8 |
| Niobium | ppm | 34–74 | 67–105 | ppm | ? |
| Fluorine | ppm | 0–0 | 1–1 | ppm | ? |
| Caesium | ppm | 2–157 | ? | ppm | ? |

**Table 3.1** (continued)

| | | Minimum and maximum concentrations | | | |
|---|---|---|---|---|---|
| | | Nodules | Crusts | | Sulphides |
| *Rare earths* | | | | | |
| Lanthanum | ppm | 36–343 | 155–224 | ppm | ? |
| Praseodymium | ppm | 25–158 | ? | ppm | ? |
| Neodymium | ppm | 35–289 | ? | ppm | ? |
| Samarium | ppm | 9–53 | ? | ppm | ? |
| Europium | ppm | 6–72 | 8–8 | ppm | ? |
| Gadolinium | ppm | 5–50 | ? | ppm | ? |
| Terbium | ppm | 4–31 | ? | ppm | ? |
| Dysprosium | ppm | 4–58 | ? | ppm | ? |
| Holmium | ppm | 5–18 | ? | ppm | ? |
| Erbium | ppm | 2–32 | ? | ppm | ? |
| Thulium | ppm | 2–20 | ? | ppm | ? |
| Ytterbium | ppm | 2–27 | 22–22 | ppm | ? |
| Lutetium | ppm | 0.2–4 | 1–1 | ppm | ? |
| *Platinum group metals* | | | | | |
| Platinum | ppb | 54–777 | 859–1304 | ppb | (<100)? |
| Palladium | ppb | 2–6 | ? | ppb | ? |
| Rhodium | ppb | 12–23 | ? | ppb | ? |
| Ruthenium | ppb | 14–21 | ? | ppb | ? |
| Iridium | ppb | 4–9 | ? | ppb | ? |
| Rhenium | ppb | ? | ? | ppb | ? |

interpreting in two main areas: primary deposits for zinc (Ge, In, Cd), copper (Te, Se, Au, Ag) and nickel (Pd, Au, Co) and secondary deposits for aluminium (Ga, Se) in bauxites and laterites and heavy rare earths in clay and associated mineral ores.

## Rare Metals and Marine Mineral Resources

Rare metal concentrations can be rather contrasting according to mineral deposits, but also according to the environments in which they are formed. Rare metals have not always been detected in samples collected over the past decades. A major analysis effort will need to be made on existing collections, in order to determine fluctuations in concentrations of rare elements and to understand concentration processes in the richest samples. However, the knowledge gained shows that several rare metals are concentrated in oceanic mineral deposits.

The base metals contained in nodules are iron (7–23 %), manganese (7–26 %), copper (292–10,200 ppm), nickel (2,600–12,800 ppm) and cobalt (2,400–8,054 ppm). These are the metals that have thus far been considered in economic estimations. Copper is found at concentrations on average twice as high as those of large copper mines operated in the Andes. Nevertheless, several studies show that nodules can be rich in light rare earths, in excess of several hundred grams per tonne (ppm). Other elements such as thallium can be present at concentrations of several hundred ppm. Nodules can also be considered as strategic reserves for base metals and certain rare metals. Several countries, including the United States and Germany, have undertaken to resume analyses of their collections of nodules using modern analytical methods in order to determine the variability in the composition of minor elements and in particular rare earths.

The chemical elements concentrated in crusts are rather similar to those of nodules. There are however variations for rare earths, platinum and cobalt which tend to be significantly more concentrated in crusts. Rare earth concentrations can reach a few thousand ppm in certain hydrogenated crusts, compared to a few hundred ppm in nodules.

Rare earths are extracted from seawater and the higher concentration in crusts is related to their lower growth rate.

Hydrothermal sulphides are characterised by very high base metal contents in relation to crusts and nodules. The sum total of copper and zinc frequently exceeds 15 %. As these are sulphide deposits, the sulphur content is very high and the iron content varies between 1 and 43 %.

Several minor elements are found alongside the main metals. Copper ore deposits, characterised by their formation at temperatures of over 300 °C, may also be rich in selenium, cobalt, nickel, molybdenum, tellurium, bismuth and gold. Zinc ore deposits, formed at between 100 and 250 °C, are often rich in cadmium, lead, arsenic, antimony, germanium, indium and barium.

Notes

1. The minimum and maximum values presented represent average values for the sites. Certain specific mineral associations can have far higher concentrations.
2. Data in brackets (2–43)? Only calculated for a few sites.
3. Many concentrations are calculated based on old analytical methods and would be worth reviewing using quicker, more sensitive methods (ICP-MS).
4. For minor and trace elements, the concentrations exploited and types of land-based deposits need to be checked.