only these elements whose minerals are described in this book. Other elements represented in nature by rare or unimportant minerals are not considered. This method of grouping is helpful both to the mineralogist determining minerals by some analytical technique, and also to the economic geologist, who may wish to know which various ores are associated with a particular element.

The groups and subgroups obtained from Table 1.8 are dealt with in the order shown in that table, and are set out below:

Group	Ia	lithium, sodium, potassium
	Ib	copper, silver, gold
Group	IIa	calcium, strontium, barium (radium)
	IIb	beryllium, magnesium, zinc, cadmium, mercury
Group	IIIb	boron, aluminium
Group	IVa	titanium, zirconium, [cerium], thorium
	IVb	carbon, silicon, tin, lead
Group	Va	vanadium, niobium, tantalum
	Vb	nitrogen, phosphorus, arsenic, antimony, bismuth
Group	VIa	chromium, molybdenum, tungsten, uranium
	VIb	sulphur, selenium, tellurium
Group	VIIa	manganese
	VIIb	fluorine, chlorine, bromine, iodine
Group	VIIIa	iron, cobalt, nickel
	VIIIb	ruthenium, rhodium, palladium, osmium, iridium, platinum

Formal descriptions of all the minerals are given either in Chapter 8, for the non-silicate minerals, using the Dana subdivisions given earlier, or in Chapter 9, for the silicate minerals, using crystal chemical subdivisions.

As in the previous editions of this book, information on elements and industrial minerals is obtained from the *Mining Annual Review* issued by the *Mining Journal*, and it is worth summarizing the arrangement of industrial minerals used in the *Review*, from which the importance, complexity and variety of mineral products in industry is immediately apparent. The arrangement is as follows:

Precious metals: gold, silver, platinum metals.
Older major metals: copper, tin, lead, zinc.

New extraction plants on the Dead Sea have increased the amount of potash recovered to over 1.5 million tonnes (Mt) per annum.

The following gives a summary of the potash production in normal years, considered in terms of the minerals exploited. Italy produces a small quantity of leucite. The overwhelming proportion of the production comes from the saline residues, with an annual output of over 29 Mt in 1985. The major producers are the USSR (10.5 Mt), Canada (6.6 Mt), East Germany (3.5 Mt), West Germany (2.6 Mt), France (1.7 Mt) and the USA (1.2 Mt), with Israel, Spain, Jordan, the UK and Italy all producing between 0.1 and 1.0 Mt per annum. Alunite is produced by Korea, Italy, the USSR, Japan, Australia and Spain. Nitre production is largely from India, where it is of organic origin, and Chile, where it is of inorganic origin in the sodium nitrate deposits.

The most important use of potash salts is as fertilizers, taking 95% of total K_2O production. Other uses are in the manufacture of special glasses, soaps and detergents.

Tests. Potassium compounds give a lilac flame coloration, which is, however, masked by sodium and other elements; the flame should be viewed through blue glass or an indigo prism, whereby elements other than potassium are eliminated. Fused potassium compounds give an alkaline reaction with litmus. For the detection of small quantities of potassium compounds in solution, a few drops of platinic chloride produce in such a solution, after prolonged stirring, a precipitate of minute yellow crystals of potassium platinochloride, K_2PtCl_6.

The potassium minerals, other than silicates, dealt with are:

chlorides	sylvine, KCl
	carnallite, $KMgCl_3.6H_2O$
	kainite, $KCl.MgSO_4.3H_2O$
sulphates	polyhalite, $K_2Ca_2Mg(SO_4)_4.2H_2O$
	alunite, $KAl_3(SO_4)_2(OH)_6$
nitrate	nitre, KNO_3

Group Ib Copper, silver and gold

Copper minerals

Copper (Cu) is a widely distributed and abundant element in combination, and is also found in the native state. The metal copper has a specific gravity

$ZnCO_3$, and hydrozincite, $Zn_5(OH)_6(CO_3)_2$, the hydrated silicate, hemimorphite, $Zn_4Si_2O_7(OH)_2.H_2O$, and sometimes the anhydrous silicate, willemite, Zn_2SiO_4. In such oxidized zones the hydrated sulphate, goslarite, $ZnSO_4.7H_2O$, often occurs as an efflorescence.

In most occurrences of zinc ore, the blende is accompanied by galena. There are several types of zinc deposit. In one very important type, illustrated by the great Tri-State field in the Mississippi Valley, galena and blende occur as metasomatic disseminations or gash, cavity or joint fillings in limestone; the ore is certainly epigenetic, but whether it was derived from below and transported by ascending solutions, or from above and carried down, is a matter for discussion. The important Broken Hill deposits occur in lodes along fault planes in a series of metamorphosed rocks, and are of hydrothermal origin. Other deposits of hydrothermal origin replace limestone and are exemplified by the Leadville field in Colorado. Other zinc–lead deposits are found as contact metamorphic deposits, but these are not very important. The ore of the famous Franklin Furnace deposit of New Jersey is franklinite, $(Fe,Zn,Mn)(Fe,Mn)_2O_4$, willemite and zincite, ZnO, and occurs as bands and lenses in crystalline limestone; this remarkable deposit is interpreted as of pyrometasomatic origin, but may possibly be a hydrothermal zinc deposit which has been subsequently contact metamorphosed. Finally, the decay of rocks such as limestones in which there are zinc–lead veins and deposits gives rise to residual deposits of these minerals.

Tests. Zinc minerals heated on charcoal give an encrustation which is yellow when hot, white when cold; this encrustation, moistened with cobalt nitrate and strongly reheated, assumes a fine green colour.

The nomenclature of some of the zinc minerals is rather confused; the sulphide is usually called zinc blende or blende in the UK, but is known as sphalerite in the USA; the anhydrous carbonate has been called calamine in the UK, but smithsonite in the USA; the hydrated silicate is hemimorphite (once called calamine in the USA). The zinc minerals considered here are:

element	native zinc (doubtful)
oxides	zincite, ZnO franklinite, $(Fe, Zn, Mn)(Fe,Mn)_2O_4$
sulphide	blende, sphalerite, ZnS
carbonate	smithsonite, $ZnCO_3$

The rare element **hafnium** (Hf) replaces zirconium in up to about 1% of zircon. Hafnium is used mainly in control rods in naval nuclear reactors and also in ceramics, refractories, alloys and in hafnium–columbium carbide cutting tools. About 50 t of hafnium was produced in the USA in 1985.

Rare earth minerals

The rare earth elements (REEs) include cerium, lanthanum, erbium, yttrium, europium and gadolinium. The most important are **cerium** (Ce), **yttrium** (Y), **gadolinium** (Gd), **samarium** (Sm) and **neodymium** (Nd). **Thorium** is associated with this group being common in monazite, a cerium-bearing mineral.

The uses of the REE oxides vary from petroleum catalysts and metallurgical uses to the manufacture of ceramics and glass. Cerium, yttrium and europium oxides are used in cathode ray and colour television tubes, and as a coating on camera lenses. Neodymium is used in high strength neodymium–iron–boron permanent magnets.

Many minerals contain REEs, and in particular orthite or allanite (a cerium-bearing member of the epidote group of rock-forming minerals), monazite (an RE-bearing phosphate containing thorium), bastnaesite (a hydrated RE carbonate), and xenotime (yttrium phosphate).

Rare earth oxides are normally obtained from bastnaesite and monazite. Yttrium is produced from monazite or xenotime. Most REEs in the USA and China are obtained from bastnaesite deposits, and in Australia from monazite deposits.

World production of rare earth ores in 1985 was estimated at 47 000 t, with the principal mineral concentrate producers being the USA (25 310 t bastnaesite), China (12 000 t bastnaesite), Australia (14 000 t monazite), Brazil (6000 t monazite) and India 4000 t monazite). Canada is about to start mining xenotime (for yttrium).

Tests. Satisfactory tests for cerium and other REEs are complicated chemical ones, and are beyond the scope of this book. Rare earth metals can be detected by spectroscopic methods. Under the microscope, the identity of grains of monazite can be established by use of the spectroscopic eyepiece, whereby characteristic absorption bands are observed.

The cerium minerals considered are:

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