



# Minerals and rock structure

Corel

*The rock cycle is responsible for the formation of many different types of rocks and minerals. This article looks at the formation of minerals, their composition and their internal structure.*

Of the 3700 minerals discovered so far, most are rare, sometimes merely a thin coating on a rock. Others, such as quartz, feldspars and calcite, are found worldwide. Some exist only as microscopic crystals; other crystals may weigh several tonnes.

Minerals are formed in a wide variety of environments. For example:

- opal forms from water percolating down near-surface joints between rocks
- gypsum forms from warm saline waters
- garnet forms at a temperature of 500°C in solid rocks 25 km below the surface
- olivine forms from magma at 1100°C, either on the surface or deep below the crust
- galena forms in veins from hydrothermal waters at depth

## How do minerals form?

The whole Earth, apart from the liquid outer core and isolated patches of magma elsewhere, is made of minerals. The chemical constituents of the Earth are continually being reworked; virtually nothing new is being made.

Eight elements — oxygen, silicon, aluminium, iron, calcium, sodium, potassium and magnesium — make up 98% of the Earth's crust by weight. Oxygen is 47% of the crust by weight and 93% by volume. Some 20 or

so mineral families make up 99% of the crust's mass. Whether a particular mineral grows or not depends on the appropriate elements being present in the right concentration under the right conditions (mainly temperature and pressure).

## Chemical composition

A few minerals contain only one element, such as gold (Au) and diamond (C), but most are compounds, such as galena which is formed of lead (Pb) and sulphur (S). Figure 1 shows the most frequently found elements in the Earth's crust. It follows that minerals which contain mixes of these elements are common, whereas minerals formed of rare elements, such as diamond which is made from carbon, are rare. Thus, rocks containing silicon are common, while non-silicon containing rocks are much less common.

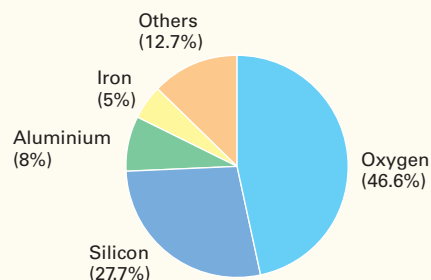


Figure 1 Composition of the Earth's crust (mass)

## GCSE key words

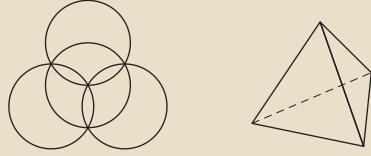
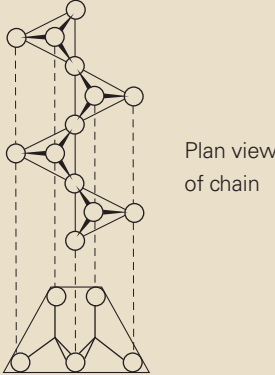
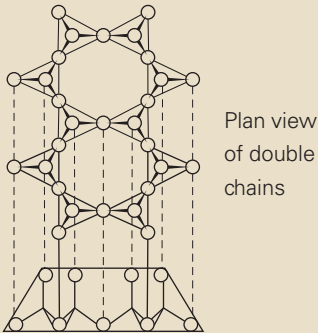
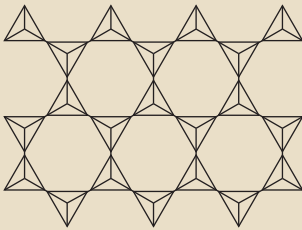
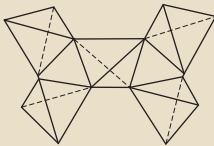
Rocks  
Silicates  
Minerals  
Diamond  
Graphite

**The oldest known mineral is zircon:** 4300 million-year-old crystals of zircon were found in a sedimentary rock in Australia which derived from an earlier igneous rock.

**Hydrothermal:** minerals dissolved in superheated water under pressure.

**Sedimentary:** rocks made by the deposition of material under water which have subsequently been cemented together.

**Figure 2** Silicates

Mineral types with examples of formula	Structural type and silicate unit
Olivines: e.g. $Mg_2SiO_4$  Garnets: e.g. $MgAl_2(SiO_4)_3$	Single tetrahedra $(SiO_4)^{4-}$   (a) Relative scale      (b) Schematically
Pyroxenes: e.g. $Mg_2Si_2O_6$	Single chains $(Si_2O_6)^{4-}$   Plan view of chain  End-on view
Amphiboles: e.g. $Ca_2Mg_5(Si_8O_{22})(OH)_2$	Double chains $(Si_4O_{11}(OH))^{7-}$   Plan view of double chains  End-on view
Micas: e.g. $KMg_3(AlSi_3O_{10})(OH)_2$ (also clay minerals)	Sheet silicates $(Si_4O_{10})^{4-}$  
Quartz: $SiO_2$ Feldspar: e.g. $NaAlSi_3O_8$	Framework silicates $(SiO_2)$  

## Physical properties

The physical properties of minerals depend on their chemical composition and structure. For example, graphite and diamond have the same composition but quite different structures and totally different properties. These properties reflect the conditions under which the diamond and graphite were formed. Diamond, which is formed under high pressure, is hard, whereas graphite, which is formed under low pressure, is soft.

Most rock forming minerals are silicates that can be bonded as isolated tetrahedras (olivines), chains (pyroxenes), double chains (amphiboles), sheets (micas) or frameworks (quartz) (see Figure 2).

## Bonds in the crystals

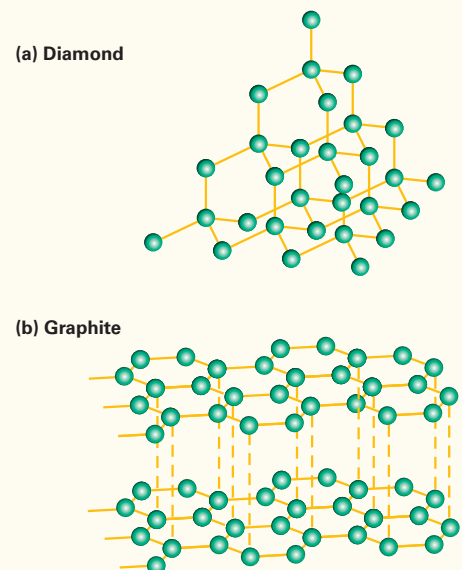
Atoms in mineral crystals are held together by electrostatic bonding forces, which in about 90% of minerals are ionic or predominantly so. An ion is an atom that has become charged, either by the loss of an electron to become positively charged, or by gaining an electron to become negative.

## Mineral hardness

The hardness of a mineral is usually measured on **Mohs' scale of hardness** (Table 1). Diamond is the hardest mineral, with a value of 10 on the scale, while talc, the softest mineral, has a value of 1.

A harder mineral can scratch a softer one but not the other way round. Hardness depends on the atomic structure of the mineral, and how densely the ions are packed within the structure. Diamond is far more tightly packed than graphite, although they have the same chemical composition (Figure 3). Similarly, within silicate rocks, micas have a hardness of 2 to 3 due to the atoms being loosely packed. In contrast, olivines with a hardness of 6.5 and quartz, hardness 7, are densely packed.

**Figure 3** Structure of (a) diamond and (b) graphite



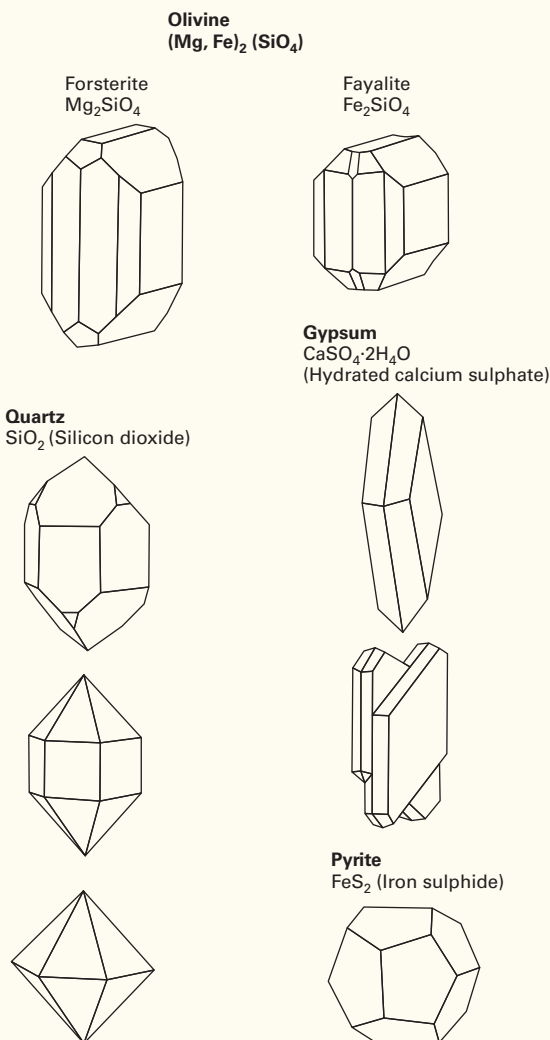
**Table 1** Mohs' scale of hardness

	Hardness	Mineral	Examples
	10	Diamond	
	9	Corundum	
	8	Topaz	
	7	Quartz	Steel file 7.5
	6	Feldspar	
	5	Apatite	Steel pin or penknife 5.5
	4	Fluorite	
	3	Calcite	Copper coin 3.5
	2	Gypsum	Finger nail 2.5
	1	Talc	

## Cleavage

Cleavage is the way in which a mineral breaks along a distinct, well-defined plane of weakness. These lines of weakness are related to the internal atomic structure – in effect, they are lines of weakness in the chemical bonds between chains and layers of atoms. Micas have well-developed cleavage direction, and the mineral splits in thin sheets. The bonds between the sheets are weaker than the bonds within the sheets.

**Figure 4** Crystal forms of some common minerals



## Box 1 Silicates

About one third of all known minerals are silicates. They are the most important rock forming minerals. Many of them are rare but there are a few types – olivines, pyroxenes, amphiboles, micas, clay minerals, quartz and garnet – which are quite common, and these make up 95% of the Earth's crust.

### Types of silicate minerals

Silicate minerals are classified according to their crystalline structure. The basic structure is one silica atom surrounded by and strongly bonded by four oxygen atoms ( $\text{SiO}_4$ ).

- **Olivines** are a group of silicates that contain magnesium, iron and the silicate group with minor amounts of nickel, manganese and calcium. Olivine is common in basalts, dolerite and gabbro.
- **Pyroxenes** are chains of silicate ( $\text{SiO}_4$ ) units. The chains are linked by cations, especially calcium, iron and magnesium.
- There are 30 or so types of **mica**, but only three are common – biotite, muscovite and phlogopite. Micas are sheet silicates. The forces between the sheets are weak and so the sheets can be split apart from one another easily. Mica is sometimes used to insulate electrical heating elements as it is not affected by heat. Formica was invented as a synthetic substitute for mica in electrical uses.

## Crystal form

Crystal form refers to the shape of the crystals. This depends on the atomic structure of the elements involved (Figure 4). When there are many elements in a mineral, crystals may interfere with the growth of other crystals, so crystal structure is not always as straightforward as the theory suggests.

## Colour and streak

Colour is one of the more obvious properties of a mineral although it can be affected by the impurities of a handful of atoms. Quartz ( $\text{SiO}_2$ ) occurs in a range of colours including colourless (rock crystal), white, pink (rose quartz), black (smoky quartz) and purple (amethyst). Hardness and cleavage are not affected by colour. Gemstones such as ruby (red) and sapphire (blue) are variations of corundum ( $\text{Al}_2\text{O}_3$ ). Streak is the colour of the mineral when powdered.

## Relative density

The relative density of a mineral is the ratio between its mass and that of an equal volume of water. Relative density depends on the atomic mass of the elements and how closely packed the atoms are. Diamond and graphite are both composed of carbon, but diamond has a high relative density (3.52) compared to graphite (2.3). Most minerals have a relative density of between 2.5 and 3.5, with the exception of minerals containing heavy metals such as barium (barite, barium sulphate  $\text{BaSO}_4$ , with a relative density of 4.5). Gold has a relative density of up to 19.3.

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**Graphite is soft because the layers of carbon atoms can slide over each other easily.**

**Diamond is hard since each carbon atom is strongly held to four others in a rigid three-dimensional network.**

**Positive ions are called cations. Negative ions are called anions.**

- Go to [www.minersoc.org/pages/links/schools.html](http://www.minersoc.org/pages/links/schools.html) and follow the links to other useful mineralogy and geology websites.