

Minerals explained I—Rock forming silicate minerals I

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Minerals Explained editor

Overview

The rocks which make up the planet we live on, the houses many of us live in and helped carve the scenery we enjoy all have one thing in common, they are all made up of minerals. Every rock type—whether it be igneous, metamorphic or sedimentary is made up of a collection of one or more of these minerals, with some being common and widespread (Fig. 1A: quartz; SiO_2), while others are rare, with most people never coming across them during their lives, (except perhaps in a museum, like Kinoite; $\text{Ca}_2\text{Cu}_2\text{Si}_3\text{O}_8(\text{OH})_4$ —see Fig. 1B). Defining what actually constitutes a mineral is not as easy as it might seem and whatever scheme is used will exclude substances which some might classify as a mineral. However, the following definition would probably be agreeable to most:

‘A mineral is a naturally occurring, usually inorganic solid with a highly ordered atomic arrangement and a definite (although not fixed) chemical composition.’

This means that in order to qualify as a mineral a substance must be found to be naturally occurring in nature and not simply generated in a laboratory. For example Baddeleyite (Fig. 2A) is a naturally occurring, although rare, mineral of zirconium oxide (ZrO_2) while cubic zirconia (Fig. 2B) is a laboratory synthesized variety of ZrO_2 , often used in the jewellery industry as a substitute for diamond, but which is not classed as a mineral.

Traditional definitions of a mineral also require them to form via inorganic processes, such as from the melts inherent to igneous rocks and via the increased pressures and temperatures that define the metamorphic regime. However, this makes the definition very restrictive and would exclude outstanding organic minerals such as oyster pearls and shells (Fig. 3A), which are virtually identical to inorganically precipitated aragonites (Fig. 3B). Other examples of minerals that can be both organic and inorganic in nature include: fluorite (CaF_2) and pyrite (FeS_2) while the human body also generates apatite ($\text{Ca}_5(\text{PO}_4)_3(\text{OH})$) in bones and teeth and oxalates (CaC_2O_4) in kidneys.

The requirement that minerals should be solid means that substances in liquid and gaseous form are excluded. Thus, where H_2O forms as ice it would be classed as a mineral but, where it is present as water it is not. Similarly, while mercury (Hg) can form naturally as a liquid metal in ore deposits it is, strictly speaking, not a mineral. To get around this, mercury is often classified as a ‘mineraloid’, a term which covers those substances that are like minerals in chemistry and occurrence but which differ in their nature. Similarly minerals must have a ‘highly ordered atomic arrangement’ and thus, they must be crystalline in nature. This further excludes liquid substances, but it also means that amorphous substances including opal (amorphous SiO_2 , discussed in this series), and volcanic glasses are not minerals but mineraloids.

Finally, in order to classify as a mineral a substance must have a definite, although not necessarily fixed, chemical composition. This basically means that a mineral should be able to be defined by a specific chemical formula i.e. FeS_2 for pyrite or SiO_2 for quartz. Many minerals or mineral groupings preserve a range of possible chemical compositions. For example, while the plagioclase group of minerals are silicates, and are known to contain Na, Ca and Al along with Si and O, the exact percentage compositions vary from 90 to 100% NaAl-Si₃O₈ in albite (Fig. 4A), and 90–100% CaAl₂Si₂O₈ in anorthite (Fig. 4B).

Rock-forming silicates

The vast majority of the common rock-forming minerals consist of combinations of the materials that are most abundant in Earth’s crust. Of all of the elements in the periodic table, it is only eight that make up nearly 99% of the atoms in the Earth’s crust: oxygen, silicon, aluminium, iron, calcium, sodium, potassium and magnesium, and of these oxygen and silicon make up nearly 85% of the total. Hardly a surprise therefore, that the vast majority of minerals in Earth’s crust are silicates, either in the purest form (SiO_2) or with the addition of the other six major metallic elements.

In terms of mineral distribution, the rocks that form Earth’s continents and continental crust are dominated by aluminosilicates (i.e. are aluminium rich), while the rocks present on the ocean floor are dominated by ferromagnesian silicates (i.e. are iron and magnesium rich). Rocks dominated by aluminosilicate minerals (i.e. plagioclase feldspar, alkali feldspar) are known as felsic rocks, while those dominated (although not exclusively), by ferromagnesian silicates (i.e. olivine, pyroxene) are known as mafic rocks. When we go deeper than the lithosphere, into Earth’s mantle, rock compositions, while similar to that of the oceanic crust, are

even more dominated by ferromagnesian silicate minerals (i.e. olivine, pyroxenes). These rocks are generally called ultramafics. It is important to realize that though these terms (felsic, mafic, ultramafic) are generally used by geologists to describe igneous rocks, what they truly refer to is the dominant rock forming mineral assemblages, rather than rock types.

The online event

In this first release for the *Geology Today* Online Event, we discuss a few of the most abundant, important and interesting silicate minerals, specifically those which are felsic in composition (i.e. quartz, opal, alkali feldspar and plagioclase feldspar).

All of these minerals are 'tectosilicates' or 'framework silicates' in that they have a three-dimensional framework of silicate tetrahedral with SiO_2 or a 1 : 2 ratio. The tectosilicates (which also includes the feldspathoid, zeolite and scapolite groups) comprise nearly 75% of Earth's crust. These minerals were selected due to their widespread abundance in all of the rock types in the Earth's crust and in terms of opal how, as a mineraloid, it differs from its sister mineral, quartz.

Mineral details

Quartz has the chemical formula SiO_2 and is the second most abundant and widespread mineral in the Earth's crust, making up, from some estimates, approximately 12% of all the minerals. This mineral abundance is not uniform, but tends to be concentrated in the continental crust and depleted in the oceanic crust and Earth's interior. Quartz is a major mineral in all three major rock groups (igneous, metamorphic, sedimentary), but is probably best known for being the primary constituent of sedimentary sandstones. Quartz occurs as transparent or translucent crystals which can be coloured by various elemental impurities—giving rise to examples which range from red and greens to purples and browns (Fig. 5A, B).

Quartz is a trigonal mineral and the ideal shape, often seen in gem and museum quality examples, is a six-sided prism, terminating with six-sided pyramids at each end. The best examples of this form and nature arise in quartz geodes where crystals grow into voids. Tridymite (SiO_2) and Cristobalite (SiO_2) are high temperature quartz polymorphs (i.e. the same chemical formula SiO_2 but a different crystal structure) often generated during volcanic eruptions while coesite (SiO_2) is a quartz high-pressure polymorph generated at depth in the Earth's crust and at meteorite impact sites.

Did you know that while quartz is only the second most abundant mineral in the Earth's crust it is the most abundant mineral at Earth's surface?

Opal, as with quartz, has the chemical formula SiO_2 and although it satisfies many of the criteria for what is classified as a mineral, it lacks an ordered atomic crystal structure due to its amorphous nature and is therefore, strictly speaking, a mineraloid. Although not a mineral as such many scientists and organizations still list opal along with the other major silicate mineral varieties. Opal is hydrous, with water making up anywhere between 3–21% of the total weight. Precipitation of opal occurs at relatively low temperature and it may form in the fissures of almost any rock type (Fig. 6A, B) although it is most commonly found associated with sedimentary sandstones and marls and igneous rhyolites and basalts. Opal's internal structure makes it diffract light; depending on the conditions in which it formed it can take on many colors. Some specimens display different colours when viewed from different angles or when the light source is moved, this feature is known as 'play of colour'.

Did you know Australia is the source of 97% of the world's opal?

Plagioclase feldspar is the name of a series of silicate minerals that all share a similar, but not fixed, chemical composition. This relationship between minerals is called a 'solid-solution' series, where the chemical composition ranges between two-end member minerals, in the case of plagioclase: albite ($\text{NaAlSi}_3\text{O}_8$) and anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$). Plagioclase feldspar (which covers all of the compositions) is the most abundant mineral in the Earth's crust and together with the other feldspar minerals makes up nearly 60% of the crust. In terms of specific mineral names, only a few of the plagioclase compositions between albite and anorthite, are well known (i.e. oligoclase, andesine, labradorite, etc) containing defined compositions and formed at well defined conditions. Plagioclase minerals are triclinic in nature, and in colour, are generally white, although where impurities arise a range of coloured varieties can occur. Plagioclase feldspars can be found in all three rock types but are most commonly associated with igneous rocks, primarily granites, generally forming characteristic lath shapes (Fig. 7A) and under the microscope multiple twinning (Fig. 7B).

Did you know the gemstone 'moonstone' is largely composed of orthoclase feldspar (Na,K)AlSi₃O₈?

Alkali feldspar also known as k-spar, potassium feldspar and **orthoclase feldspar** is one of the most common silicate minerals in Earth's crust and has the formula KAlSi₃O₈. Orthoclase is also the potassium end-member mineral in the solid-solution series with the plagioclase feldspar mineral albite (NaAlSi₃O₈). Intergrowths of orthoclase and albite, generated via slow cooling in Earth's crust, result in the exsolution, mineral texture known as perthite (Fig. 7C). The high temperature polymorph of orthoclase is sanidine, often found associated with volcanic glasses, while low temperature polymorphs include microcline and adularia, the latter of which is generally found associated with hydrothermal ore deposits. Orthoclase is a monoclinic mineral and specimens often display simple twinning, as opposed to multiple twinning in the plagioclase variety (Fig. 7A). Orthoclase feldspar is a common constituent of granitoids and other igneous rocks (Fig. 7D), often forming large, lath-like crystals.

Did you know mono-mineralic rocks made up of more than 90% plagioclase are called anorthosites?

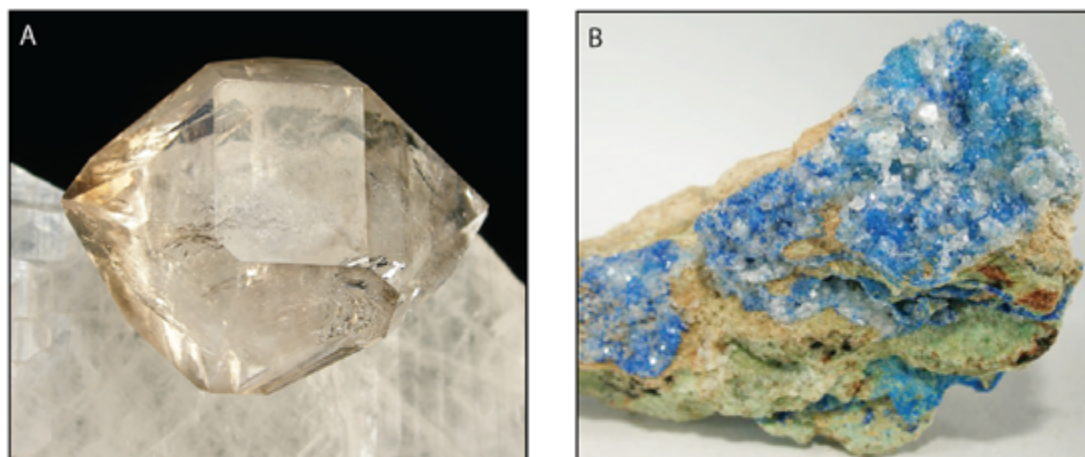


Fig. 1. **A.** 3.25 cm across double-terminated quartz crystal hosted on the surface of a quartz shard (locality Diamantina Southeast Region, Brazil). **B.** Vivid, azure-blue kinkite microcrystals festooned on sparkling apophyllite-coated vuggy matrix, size $5.6 \times 3.2 \times 2.3$ cm (locality: Christmas Mine, Arizona, USA).

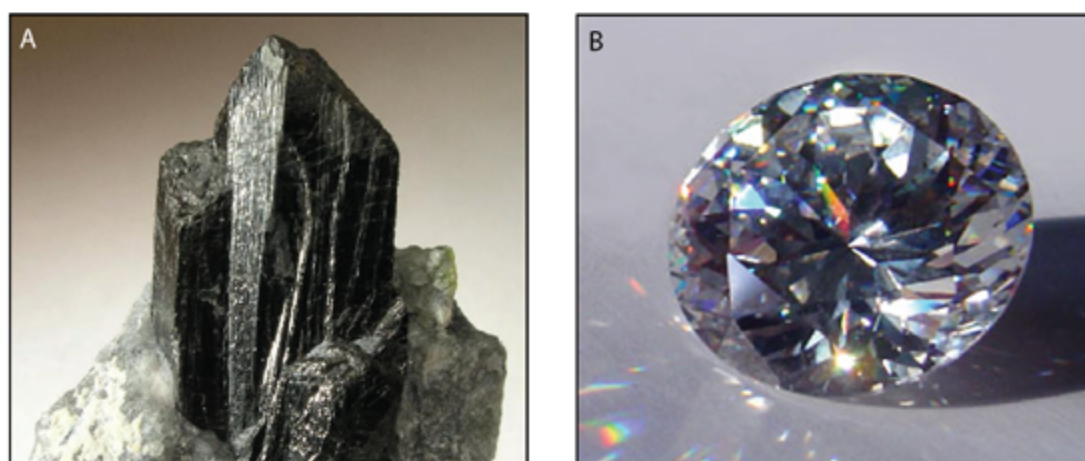


Fig. 2. **A.** A world-class baddeleyite specimen with exceptionally sharp form and good lustre, size $2.5 \times 2.2 \times 1.0$ cm (locality: Phalaborwa, Limpopo Province, South Africa). **B.** A round brilliant-cut cubic zirconia.

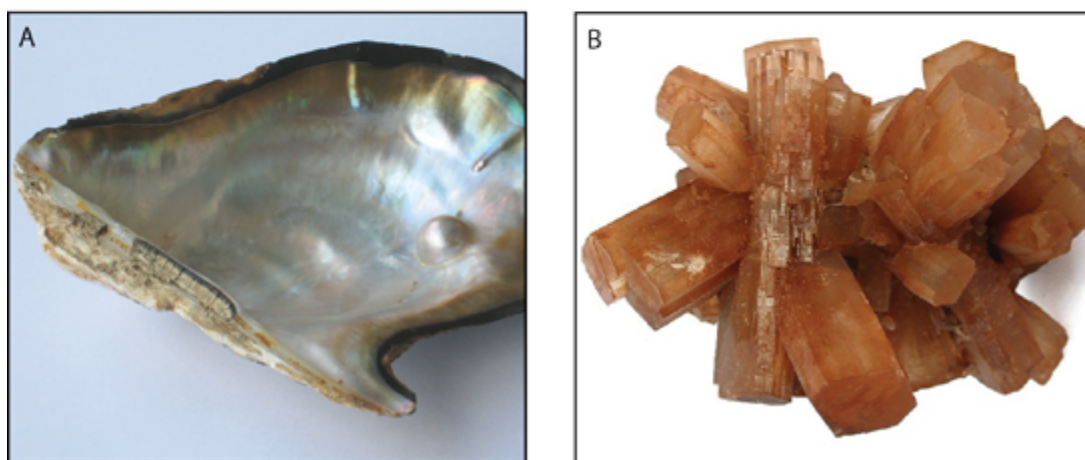


Fig. 3. **A.** An example of an organically generated aragonite pearl in an oyster shell. **B.** An example of an intergrown cluster of lustrous and translucent, ochre-coloured crystals or aragonite, size $6.0 \times 5.1 \times 4.3$ cm (locality: Tazouta Mine, Morocco).

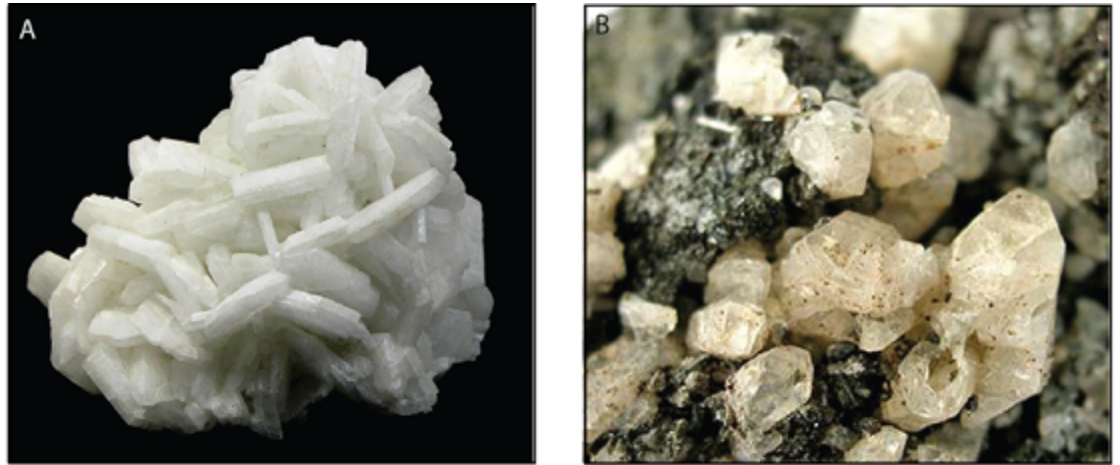


Fig. 4. **A.** A rosette of snowy, bladed albite crystals from the Richard Hauck collection, size $8.2 \times 6.8 \times 6.2$ cm (locality: Minas Gerais, Brazil). **B.** Lustrous, translucent white anorthite crystals, hosted on a basalt matrix, this sample is from the type locality for anorthite, size $6.9 \times 4.1 \times 3.8$ cm (locality: Somma-Vesuvius Complex, Campania, Italy).

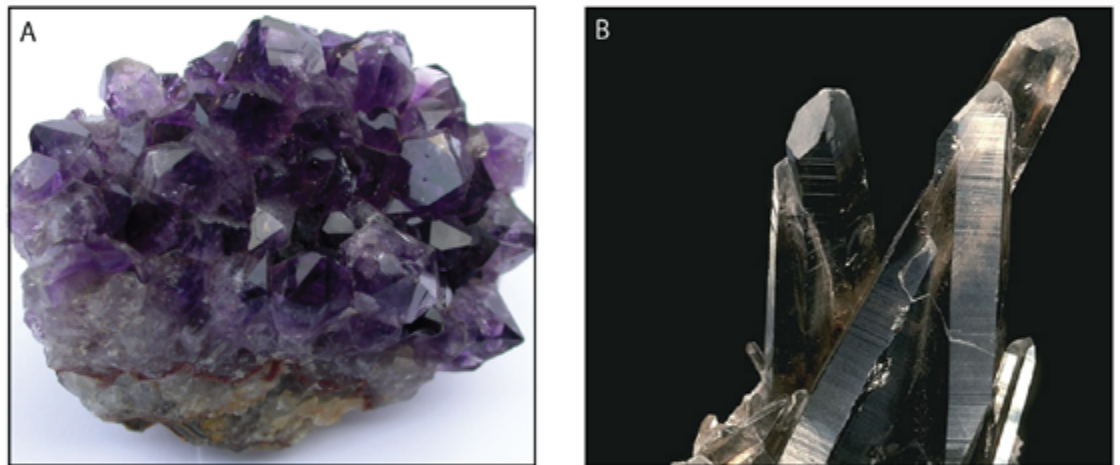


Fig. 5. **A.** An example of the 'amethyst' variety of the mineral quartz. **B.** An example of the 'smokey' variety of the mineral quartz.

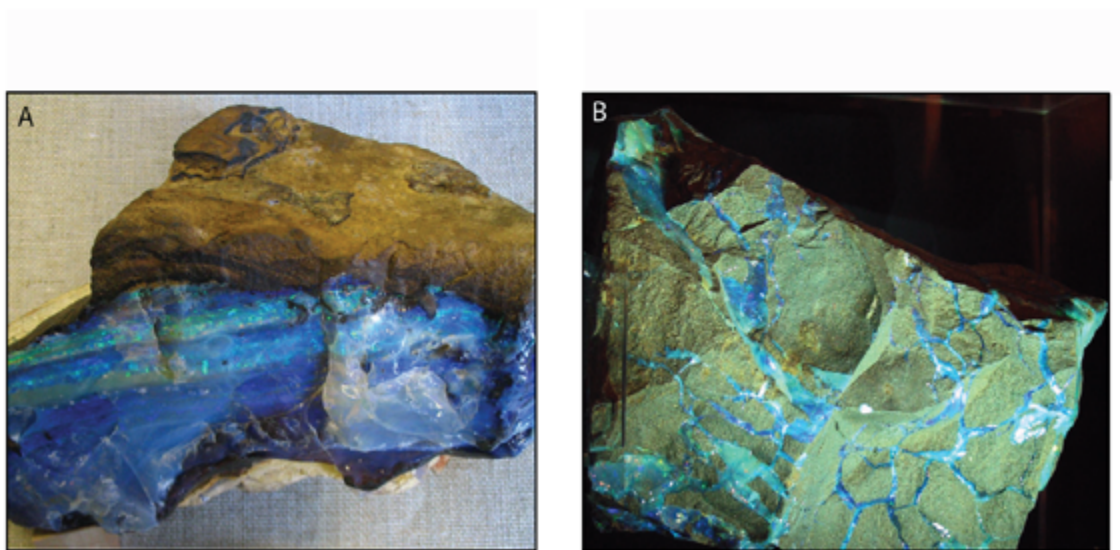


Fig. 6. **A.** A specimen of massive blue, banded opal (locality: Barco river, Queensland, Australia). **B.** Blue-green opal veins in Fe-rich rocks from Australia.

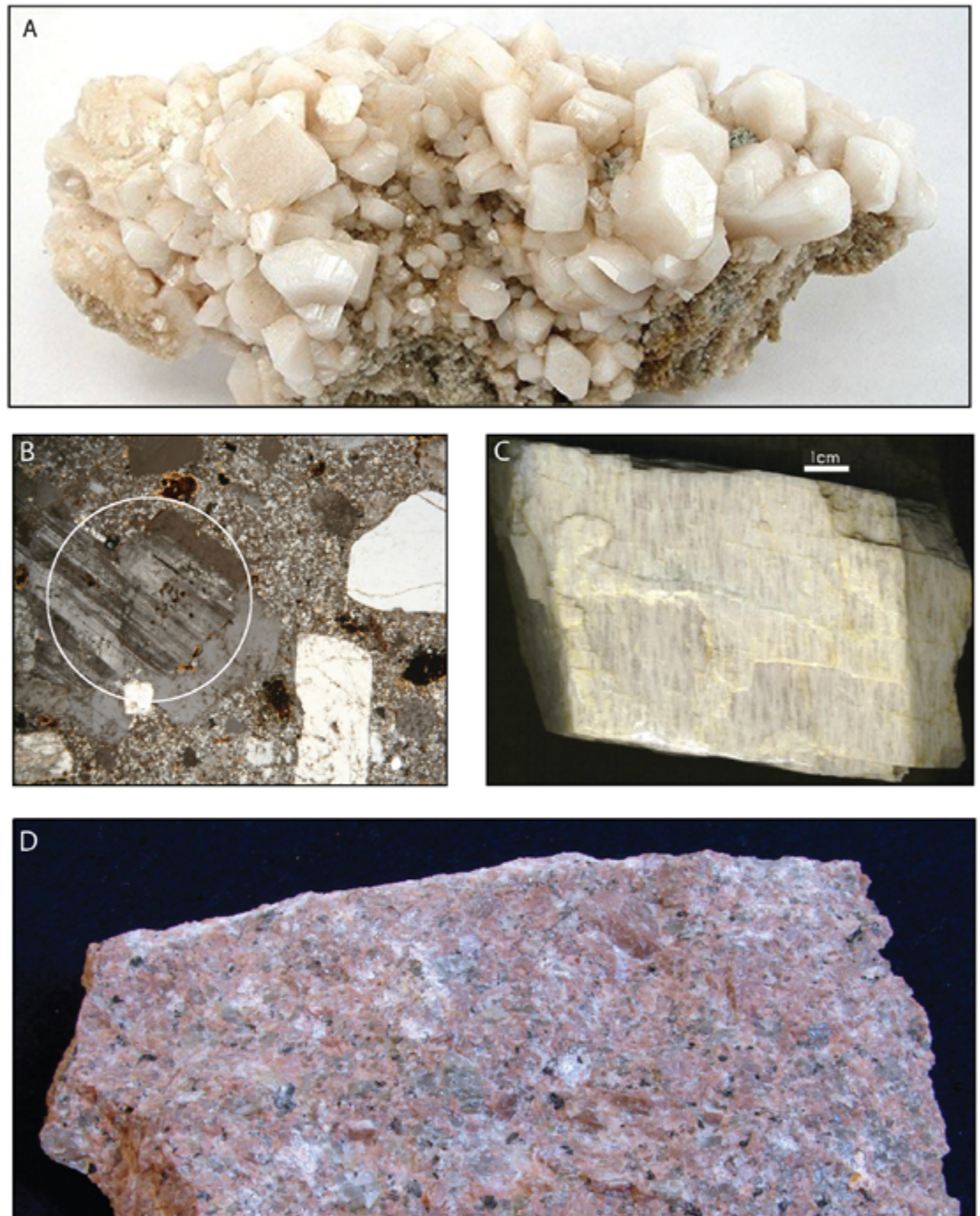


Fig. 7. **A.** Albite variety of plagioclase feldspar showing well defined, lustrous, lath like crystals (locality: Gamsberg, Namibia). **B.** Cross polarised (XPL) light image of a rhyolitic, igneous rock containing plagioclase which shows obvious multiple twinning (circled). **C.** Intergrown perthitic texture between albite and orthoclase feldspar (locality: Dan Patch pegmatite, Black Hills, South Dakota, USA). **D.** Alkali feldspar minerals rimmed by oligoclase feldspar (rapakivi texture), locality: Salto, Brazil.

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