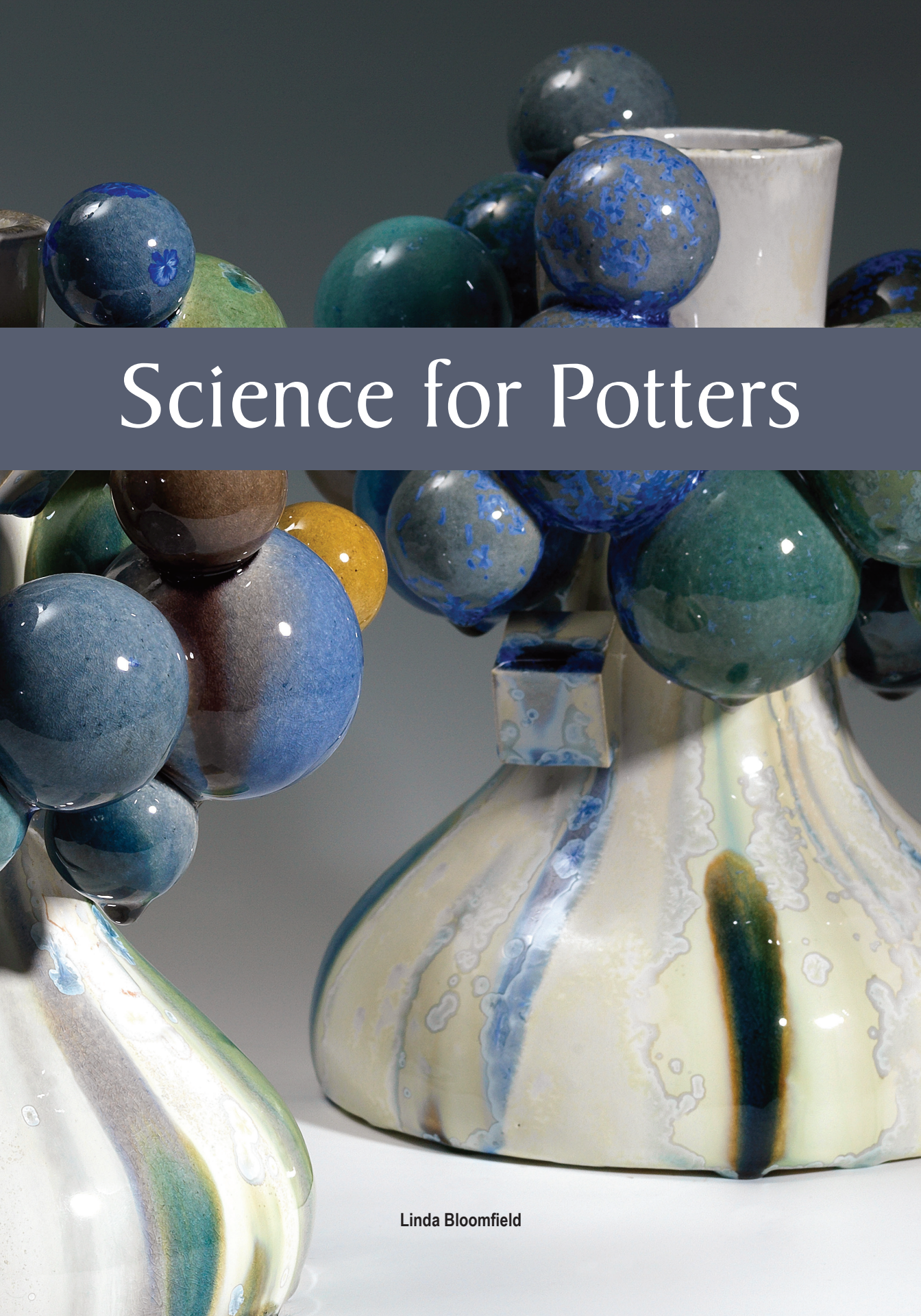


The image is a composite of two photographs of ceramic art. The top photograph shows a cluster of glossy ceramic spheres in shades of blue, green, and brown, some with speckled patterns, next to a plain white ceramic cup. The bottom photograph shows two large, bulbous ceramic vessels with complex, multi-colored glazes in shades of blue, green, yellow, and brown, with a small square ceramic piece resting on top of one of them.

Science for Potters

Linda Bloomfield

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Geology for Potters

My father used to take me on rock hunting expeditions to Aust Cliff under the old Severn suspension bridge which joins England to Wales. The cliff has visible layers of red marl, tea green marl, and limestone. We found interesting rocks, fossils, and quartz crystals. When I started my first pottery studio and bought my first glaze materials I was living in California. I thought the names of the materials sounded very exotic, Custer feldspar from the Wild West and Edgar Plastic Kaolin (EPK) from Florida. Potters in Britain are more likely to use Cornish Stone and English China Clay, both found in Cornwall (see US/UK conversion table) (p. 65).

While writing this book, I researched geology, particularly the clays and rocks of England where I live, and the clays of eastern North America, where I was born. I have concentrated mainly on the geology of Great Britain and North America, which were once joined together and share similar features. However, materials similar to those covered in this chapter can be found worldwide and the natural processes which create and transform them are universal.

In this chapter, we will explore rocks, minerals and how they are formed from magma in the Earth's crust, and recycled through weathering and sedimentation. Many rocks are millions of years old, formed by the cooling of molten rock, either deep underground or at the surface in volcanic eruptions. The movement of tectonic plates causes the uplift of mountain ranges, which are gradually weathered by water, ice and wind. The weathered rock is deposited in layers and is eventually compressed and hardened into new rock. Many of these layers include clay, sand, and other glaze materials. When potters fire their clays and glazes in a kiln, they are enabling processes similar to those taking place when rocks are formed from molten magma. The temperature of magma ranges between 1292–2372°F (700–1300°C), the same temperature range as in a potter's kiln.

Rocks are composed of minerals, many of which are crystals with ordered atomic structures (see chapter 1). We will investigate the minerals used by potters, particularly those used in glazes such as feldspar, which comes from granite rock. The structure and properties of clay will be covered in more depth in chapter 3.

Clays and glazes are made of rocks and minerals from the Earth. Potters in the past used locally available materials such as locally dug clay and pulverized rocks, wood ash, and grass ash. This use of local materials led to many different names for clays and feldspars. Minerals used by the ceramic industry are now widely available to potters

and it is useful to know their properties, as well as which materials can be substituted for others. Manufacturers will often make a synthetic version of a local material which is no longer mined. If we can understand the processes by which rocks and minerals were formed, it will help us to understand how clays and glazes melt during firing in the kiln.

Defining the Terms

Felsic: Light rock or mineral containing feldspar and silica.

Igneous: Rocks formed from cooled magma.

Magma: Molten rock.

Mafic: Dark rock or mineral containing magnesium and iron.

Metamorphic: Rocks formed from other rocks by pressure or heat.

Mineral: An inorganic substance with an ordered atomic structure e.g. quartz.

Rock: An aggregate of minerals, for example granite.

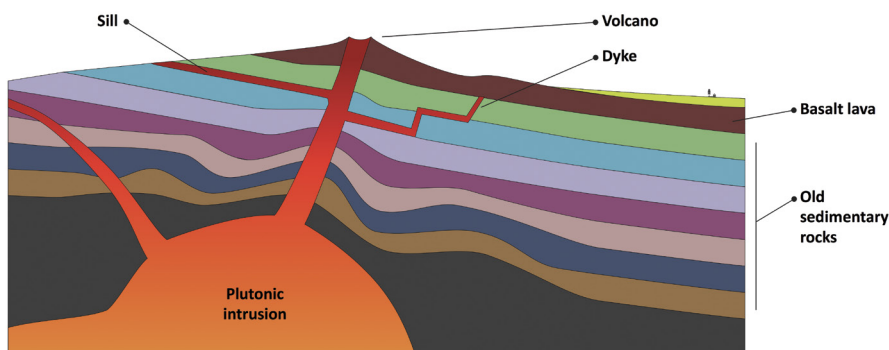
Sedimentary: Rocks formed from deposited layers of sediment.

ROCKS

The most abundant elements in the Earth's crust are oxygen and silicon. Many rocks therefore contain silicate minerals, such as feldspar, which is an aluminosilicate (containing alumina and silica). Silicates can be divided into two types, the light and the dark silicates. The light-colored silicates include quartz and feldspar, which are the main constituents of granite and are used by the ceramic industry in both clays and glazes. The dark-colored silicates contain iron and magnesium and include minerals such as olivine and pyroxene. These make up the darker rocks such as fine-grained basalt and coarse-grained gabbro, which are sometimes used by potters, particularly those making glazes from locally sourced rocks. The aluminosilicates vary in structure according to how they are formed. Granite and basalt are both types of igneous rock, made by cooling and solidification of magma, either

deep underground or from a volcanic eruption or lava flow. As the magma gradually cools, the solid igneous rock it forms changes in composition as a variety of minerals solidify from the melt, one after the other. In pottery, we often use the lighter colored, more easily melted rocks mined to produce the whiter ceramics favored by industry. In cooling magma, the magnesium, iron, and calcium crystallize out first, forming dark

green-colored olivine (a group of minerals ranging from Fe_2SiO_4 to Mg_2SiO_4) and pyroxene (minerals ranging from $\text{FeCaSi}_2\text{O}_6$ to $\text{MgCaSi}_2\text{O}_6$). These ferro-magnesian silicates are heavier and have higher melting points than the lighter silicates in the magma, although once melted they are more fluid. The remaining liquid magma is high in sodium, potassium, and silica and this crystallizes as light-colored feldspar and quartz. This is lighter in weight, but more viscous, and often flows from large underground masses called plutons into cracks between other rocks, called sills (horizontal) and dykes (vertical). The light-colored silicates contain over 65% silica and are acidic. Intermediate rocks such as syenite and diorite can contain 55–65% silica. The dark-colored silicates contain only 45–55% silica and are therefore more alkaline. Silica is classified as an acidic oxide even though it is not readily soluble in water.



2-1. Diagram of volcano, plutonic intrusion, sills, and dykes.

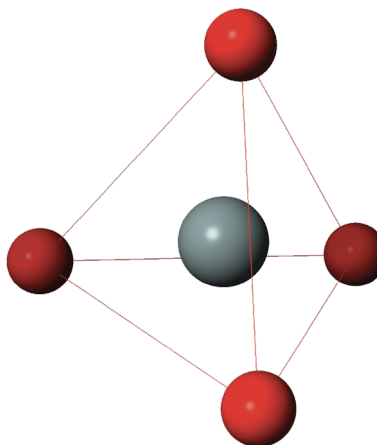
The most unstable minerals, which break down and weather most easily, are the ones with the highest crystallization temperature. This is because they form single crystal structures rather than more stable frameworks. Olivine is the least stable and quartz is the most stable silicate mineral and therefore the least weathered. The dark silicates break down to the smallest particles, found in many clays such as bentonite, whereas quartz is often found in large crystals. The structure of silica (2-3) (and all silicates) is based on a tetrahedron (a triangle-based pyramid), with a silicon atom in the center and oxygen atoms at each of the four corners. In the dark (mafic) silicates such as olivine, each isolated silica tetrahedron is bonded with magnesium and iron, rather than with other silicon atoms. The magnesium and iron form ionic bonds,

Silicates	Order	Mineral	Formula	Structure
Dark (Mafic)	1	Olivine	FeMgSiO_4	Single tetrahedron
	2	Pyroxene	$\text{MgCaSi}_2\text{O}_6$	Single chain
	3	Amphibole		Double chain
	4	Biotite mica		Sheet
Light (Felsic)	1	Calcium feldspar	$\text{CaAl}_2\text{Si}_2\text{O}_8$	Framework
	2	Ca-Na plagioclase feldspar	$\text{NaAlSi}_3\text{O}_8$	Framework
	3	K orthoclase feldspar	KAlSi_3O_8	Framework
	4	Muscovite mica		Sheet
	5	Quartz	SiO_2	Framework

2-2. Amount of silica in each mineral. Bowen's reaction series. The order in which minerals solidify from magma. The amount of silica in each mineral increases from the dark to the light silicates.

which are less stable than the covalent bonds within the silica tetrahedra. Going from darker to lighter silicates, the silica tetrahedra are bonded in increasingly stable arrangements. In pyroxene, the silica tetrahedra are bonded together in chains, while in amphibole the chains join together to make double chains. In biotite and muscovite mica, the silica tetrahedra make up whole sheets. The underlying atomic structure is scaled up in the crystalline structure of mica, which forms pseudo-hexagonal plates visible to the eye. Mica breaks down to form illite clay, which has a similar sheet structure.

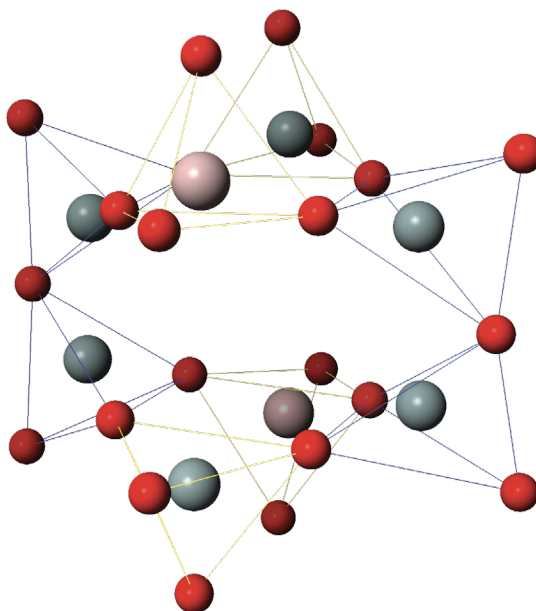
In feldspar (2-4) and quartz the silica tetrahedra are connected in three dimensions to form a framework structure, which is very stable. In feldspar, one in every four silicon atoms is replaced by aluminium and the larger spaces in the



2-3. Silica tetrahedron, gray=silicon atom, red=oxygen atom.

structure are filled by sodium or potassium atoms. The difference in valence between the silicon and aluminium is compensated by the sodium or potassium.

Rocks can be classified into three types: igneous, metamorphic, and sedimentary. Igneous rocks are those which are formed from cooled magma. If the molten rock cools slowly deep beneath the earth's surface, the crystal size will be large and



2-4. Feldspar structure, gray=silicon atom, red=oxygen atom, brown=aluminium atom. The sodium and potassium atoms are not shown but would be situated in the large spaces in between rings of silica tetrahedra. *Image: Elin Barrett.*

the granite coarse (2-5). This is known as plutonic or intrusive rock as it is often found in dykes intruding into other rocks. If the mineral crystals are very large (greater than 2 cm), the rock is called pegmatite and some types contain feldspars useful to potters. If magma cools quickly at the earth's surface, the crystals will be much smaller and the rock will have a finer grain size. This type of rock is known as volcanic or extrusive and includes light rhyolite (2-6) and dark basalt (2-7), formed from cooled lava (2-8 and 2-9). Rocks which are erupted by volcanoes can cool very fast and include frothy pumice, vesicular basalt, and glassy obsidian (2-10 and 2-11).



Science for Potters covers those aspects of science which are useful to potters and which help to give a deeper understanding of ceramic materials and processes. Aspects of geology, chemistry, and materials science are covered where relevant to potters. The properties of clays are explained by examining their chemistry and structure. The various rocks and minerals used in glaze making are explored. There are clearly explained science basics, including the elements, the structure of the atom, how atoms combine to make compounds, and why some compounds can be used to make colored pigments and glazes. The deeper understanding of materials, their structure, composition, origins, and how they interact will give potters greater control over and new insights into their craft.

About the Author

Linda Bloomfield was born in Ithaca, New York. She grew up in England and studied engineering at Warwick University, with a year at MIT during her PhD studies. She spent a year in Tsukuba, Japan, working for NEC (Nippon Electric Company), then returned to London to work as a researcher at Imperial College. She started her pottery career while living in California, where she became familiar with US potters' materials. She now lives in London where she makes porcelain tableware, teaches glaze courses, and writes pottery books.

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