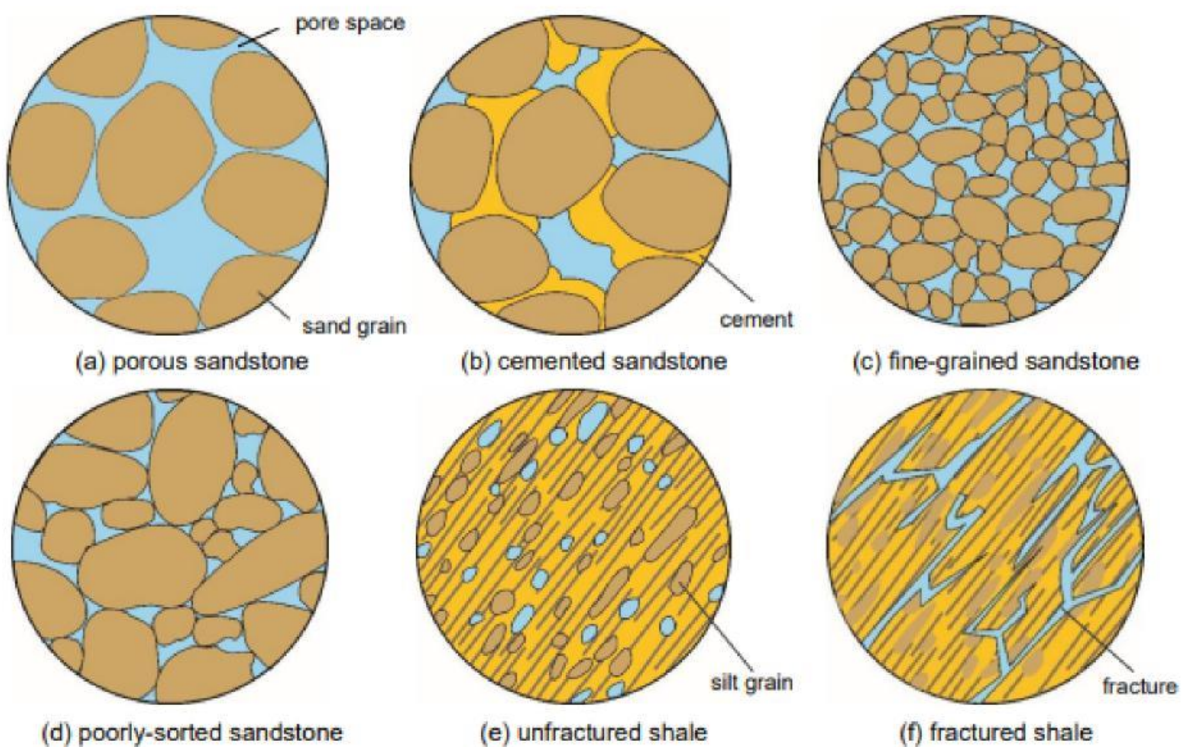
4.1.1.2 Rocks

Rocks are naturally formed substances. They are made of minerals, fragments of other rock, or fossils and are formed through the rock cycle processes. Rocks are identified and described based on their chemical composition and their physical texture. The chemical composition is linked to the minerals that form the rock, while the texture of the rock depends on the types and sizes of particles and how they are arranged. These features link in turn to the resistance of rocks to being worn away, and to their porosity and permeability.

Porosity is the amount of space or pores in a rock, measured as a percentage. 15% porosity is a high porosity for rocks; most rocks have porosities much lower than this. The permeability of rock measures how quickly fluids can flow through rocks. Rocks with high porosity have high permeability if the pores are large enough for fluids to flow through and the pores are linked together. Rocks with very small pore spaces, like clays, do not allow fluids to pass through, and are therefore porous but impermeable. Similarly, the gas bubble holes in some lavas are not joined, so the rock again is porous but impermeable (Figure 4.1) . Rocks made of interlocking crystals, or which are well-cemented or very fine-grained, stop fluids flowing through and are impermeable, unless they contain cracks and fractures. Porosity and permeability control the amounts of natural fluids such as water, oil and gas that can be stored in and flow through rocks.

Figure 4.1. Porosity and permeability in rocks. The porosity and permeability in (a) has been reduced by cement in (b); permeability in (c) is quite low because the pore spaces are small; permeability in (d) is also low because the pore spaces between larger grains have been filled by smaller ones; the unfractured shale in (e) is impermeable until it is fractured in (f).



Rocks formed of grains that are compressed together and/or naturally cemented together are sedimentary rocks – these can have a range of compositions and textures. The most common sedimentary rocks are rich in quartz, feldspar and clay minerals. These can have a range of grain sizes from coarse-grained conglomerates (with rounded grains) and breccias (angular-shaped grains), through medium-grained sandstones, to fine-grained sedimentary rocks such as mudstones, shales and clay/claystone. Limestones are also common sedimentary rocks and are formed mainly of fragments of calcium carbonate minerals like calcite, mostly from broken shells. Limestones can be identified because calcium carbonate reacts with dilute acid – a drop of hydrochloric acid on limestone will produce a fizzing reaction. Limestones also range from coarse to fine-grained and in colour from grey, to cream-coloured, to the white of fine-grained chalk.

Igneous and metamorphic rocks are formed of interlocking crystals which normally make them very resistant to being worn away and also make them impermeable, unless they are fractured. In coarser examples, the interlocking crystals can be seen by eye or with a hand lens. Igneous rocks were once molten rock called magma, and usually formed as the magma cooled down. As the magma cooled, crystals of minerals grew until they interlocked, as the rock became solid. Minerals of different compositions have different colours and crystallise at different temperatures, so igneous rocks are mixtures of minerals of different colours, shapes and sizes.

Metamorphic rocks are formed from sedimentary, igneous or older metamorphic rocks by metamorphism caused by increases in temperature, pressure or both. They form in the solid state, so there is no melting (rocks formed by melting are igneous rocks). The increase in temperature comes either from baking by a nearby magma, or from becoming deeply buried. Where pressure is involved, metamorphic rocks can only form in plate collision situations and not simply by the burial pressure of thick overlying sequences of rock. Metamorphic rocks produced by increased temperature alone have randomly-orientated interlocking crystals, whereas metamorphic rocks formed by increased plate-tectonic pressures have interlocking crystals which are orientated at right angles to the pressures. Marble, being a metamorphic rock formed of calcium carbonate crystals, reacts with dilute hydrochloric acid in the same way as limestone.

These properties enable the three great groups of rocks to be distinguished from one another: by studying the grains or crystals, by testing permeability (through dropping water onto the surface or by putting specimens into water and watching for rising bubbles), and by scratching the rocks with a fingernail or a piece of metal, such as a coin.

Table 4.2. The results of simple tests to distinguish the three main rock groups

Observation/test Rock group	Examination of grains/ crystals	Permeability test	Scratch test
Sedimentary	Grains cemented or compressed together	Water sinks in or streams of bubbles rise from specimen, unless fine-grained or well-cemented	Easily scratched unless well-cemented
Igneous	Crystals interlocking, randomly orientated	Water does not sink into surface; bubbles do not rise from specimen	Difficult to scratch unless well-weathered
Metamorphic	Crystals interlocking; randomly orientated if formed mainly by heat; parallel or sub-parallel if formed by pressure and heat together		

4.1.1.4 Sedimentary rocks

Sedimentary rocks were laid down as sediments and are identified using their mineral composition and grain size (Table 4.4). Sedimentary rocks are usually permeable unless they are well-cemented or fine-grained, and most are easy to scratch. The grains are easy to see in sand-grade rocks, but usually impossible to see in mud-grade rocks, even with a hand lens.

Table 4.4. Classification of sedimentary rocks

Chemical composition		Silicon-rich	Calcium carbonate-rich	Sodium chloride-rich	Carbon-rich
Characteristics		The most common sedimentary rocks; resistant if well cemented, otherwise easy to scratch; commonly dark or pale grey, brown, cream or red	React with dilute hydrochloric acid; easy to scratch; commonly pale grey, cream or white	Made of halite with salty taste; cubic crystals; very easy to scratch; pink, white or colourless	Very easy to scratch; often break into cubic shapes; black; may contain plant fossils
		Common rock types – see Table 4.5			
Grain size	Fine < 0.0625 mm	Mudstone; shale; clay; claystone	Limestone; chalk	Rock salt	Coal
	Medium 0.0625 – 2 mm	Sandstone; siltstone	Limestone		
	Coarse > 2 mm	Conglomerate; breccia			

Most sand-grade sediments are laid down in beds, whilst muds are deposited in thinner layers called laminations. As the sediment became buried, muds became compressed into more compact mudstones, shales or clay stones and lime mud was compressed into limestone or chalk, as water was squeezed out. Meanwhile water flowed through the pore spaces of coarser sediments, such as pebble beds, sands and shell sands, and minerals crystallised from the water as natural cement, which glued the grains together; these sediments became lithified into coarse-grained conglomerates and medium-grained sandstones or limestones, as shown in Table 4.5. So, for sedimentary rocks, the two main rock-forming processes are compaction and cementation.

Table 4.5. Common sedimentary rocks

Sedimentary rock	Images		Source of exposure image
	Specimen	Exposure	
Conglomerate			Conglomerate exposure, near San Sebastian, Spain Cretaceous age
Cream sandstone			Cross-bedded cream sandstone, Isle of Bressay, Shetland Islands, UK Devonian age
Red sandstone			Red Navajo sandstone in Antelope Canyon, Arizona, USA. The red colour is due to the hematite iron cement Triassic/Jurassic age
Mudstone			Permian red mudstone with paler siltstone beds, Bassin de Lodève, Hérault, la Lieude, Mérifons, France

4.1.1.5 Igneous rocks

Igneous rocks formed from once-molten magma, either as the magma cooled and crystallised or as it erupted explosively from a volcano. Most igneous rocks are impermeable and resist scratching because of their interlocking crystals; they are identified using their crystal size and chemical composition. The crystals in coarse-grained rocks are easy to see, those in medium-grained rocks need a hand lens, and the crystals in fine-grained rocks are usually impossible to see without a microscope. Coarse-grained rocks formed by slow cooling of magma deep beneath the surface are called plutonic rocks; fine-grained igneous rocks were erupted as volcanic rocks.

The chemical composition of the rock is linked to the minerals present and these produce the overall colour of the rock. Rocks that are rich in iron and magnesium have dark-coloured iron/magnesium-rich minerals whilst silicon-rich rocks have mainly pale-coloured minerals like feldspar and quartz. This gives the classification system in Table 4.6.

Table 4.6. Classification of igneous rocks

Chemical composition		Iron/magnesium-rich	Intermediate	Silicon-rich
Characteristics		Dark minerals; dark in colour; higher density (feel heavy)	Intermediate characteristics	Pale minerals; pale in colour; normal rock density
		Common rock types – see Table 4.7		
Crystal size	Fine (< 1mm)	Basalt	Andesite	Volcanic ash
	Medium (1-3mm)	Dolerite	Uncommon	Uncommon
	Coarse (>3mm)	Gabbro	Uncommon	Granite

Table 4.7. Common igneous rocks

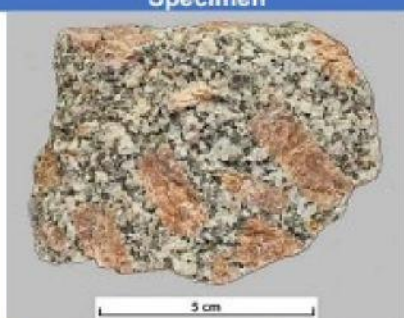
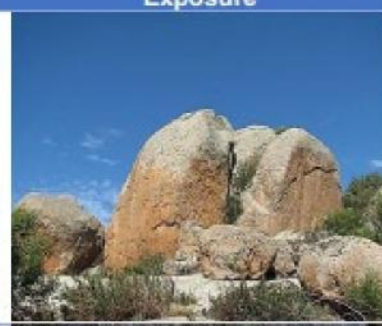
Igneous rock	Image: Specimen	Image: Exposure	Source of exposure image
Granite			Granite exposures, Mount Hope, Victoria, Australia Devonian age
Gabbro			Gabbro from the Ukraine in a geological wall in the Botanical Folk Park, Blankenfelde Pankow, Berlin, Germany
Dolerite			Dolerite dyke on the edge of a river, Agwa Rock, Lake Superior Provincial Park, Canada

Table 4.7. Common igneous rocks, continued

Igneous rock	Image		Source of exposure image
Basalt			Basalt columns (formed as the basalt cooled) at the Giant's Causeway, Northern Ireland Tertiary age

4.1.1.6 Metamorphic rocks

Metamorphic rocks are formed when sedimentary, igneous or older metamorphic rocks recrystallize in the solid state under increased heat and/or pressure. Rocks do not melt during metamorphosis; otherwise, they would become igneous rocks.

Most metamorphic rocks result from the increased heat and pressure of the mountain-building caused by plate collision. This is regional metamorphism. Under the intense conditions, some minerals are transformed into other minerals, some minerals re-crystallize to become thinner and longer, while other minerals rotate until they are lined up at right angles to the direction of the pressure.

Metamorphic rocks also form when rocks are baked by a nearby hot igneous body. Since the mineral re-crystallisation here is mainly by heat, and there is no tectonic pressure, the crystals in the new rocks are randomly orientated.

The type of metamorphic rock formed either by heat and pressure or mainly by heat depends on the make-up of the rock it originally came from, as in Table 4.8

Table 4.8. Classification of metamorphic rocks

Mineral composition		Quartz and clay minerals in mudstone or shale	Quartz in sandstone	Calcite in limestone
		Common regional metamorphic rock types – see Table 4.9		
Increase in heat and pressure ↓	Low-grade	Slate	Metaquartzite (or quartzite)	Marble
	Medium-grade	Schist		
	High-grade	Gneiss		
		Common thermal metamorphic rock types		
Increase in heat		Hornfels	Metaquartzite (or quartzite)	Marble

Since metamorphic rocks are made of interlocking crystals, they are usually impermeable and resist scratching more than most sedimentary rocks. The regional metamorphic rocks can be identified from their aligned minerals. In fine-grained slate, they produce weaknesses in the rock, which can be broken into thin sheets along the weaknesses or cleavage planes. In coarser-grained schist, the aligned minerals can be seen reflecting the light in flashes when a specimen is moved. The minerals form bands in gneiss; sometimes the bands are deformed into complex folds.

Table 4.9. Common metamorphic rocks

Metamorphic rock	Images		Source of exposure image
	Specimen	**Exposure**	
Slate			Slate in a road cutting protected by rock anchors and wire mesh, Rothaar Mountains, North Rhine, Germany Devonian age

Reference: 2023 NCF-Envirothon New Brunswick Soils and Land Use Study Resources