Properties Used to Identify Minerals

Colour

Generally, colour alone is not diagnostic in mineral identification because colour can be highly variable. Some minerals, such as quartz, calcite, or fluorite, can occur in almost every possible colour due to impurities in the chemical makeup of the mineral. However, some minerals can be easily identified by their diagnostic colours, such as pyrite (fool's gold – brassy coloured) or azurite (deep blue). Colour can be used to narrow down possible mineral identification but should not be relied upon as the sole property for identification. An example image below shows the major different varieties of the mineral quartz, and you can see, they are all very different colours, showing how colour is not a diagnostic property for the mineral quartz.

Image from https://www.geologyin.com/2016/04/major-varieties-of-quartz.html

Hardness

The Mohs scale of mineral hardness is a qualitative scale from 1 to 10 characterizing scratch resistance of common minerals through the ability of harder material to scratch softer material. Hardness is tested using a variety of objects with known Mohs hardness:

- Fingernail → 2.5
- Copper nail → 3
- Glass plate → 5.5
- Steel nail → 6.5
- Porcelain plate → 7

The hardness of possible unknown minerals is listed in the guidebook below. There are lots of free videos on YouTube demonstrating how to test hardness. Three examples are https://www.youtube.com/watch?v=MorDV1LGTqQ, https://www.youtube.com/watch?v=1Eizqc2NRz4, and https://www.youtube.com/watch?v=tJOqcdbWFw0.

Streak

Streak is the colour of powder a softer mineral leaves behind when dragged across a porcelain plate. Many minerals have a different colour when powdered than they do in crystalline or massive form. Non-silicate minerals typically leave a coloured streak, whereas silicate minerals typically have a white streak.

There are lots of free videos on YouTube demonstrating how to test the streak of a mineral. One example is https://www.youtube.com/watch?v=ngM-xww9Aps.

Cleavage/Fracture

Cleavage describes how a crystal breaks when subjected to stress on a particular plane. If part of the crystal breaks due to stress and the broken piece still has a smooth plane and reflects light, the mineral has cleavage. Minerals may also fracture, usually meaning there are no distinct cleavage planes. A common example of fracture is the mineral quartz, which exhibits conchoidal fracture. Examples of cleavage types can be seen below:

- Basal, or one direction of cleavage (like pages in a book) → Biotite
- 2 directions of cleavage at 90° → Feldspar
- 3 directions of cleavage at 90° (cubic) → Halite
- 3 directions of cleavage at 60° and 120° (rhombohedral – not at 90°) → Calcite
- 2 directions of cleavage at 56° and 124° (prismatic- not at 90°) → Hornblende
- 4 directions of cleavage (octahedral) → Fluorite
- 6 directions of cleavage (dodecahedral) → Sphalerite

Note: minerals with 4 or 6 directions of cleavage are not common.

There are lots of free videos on youtube demonstrating how to identify the cleavage planes in a mineral. Two examples are https://www.youtube.com/watch?v=1SGC3VBQZY0 and https://www.youtube.com/watch?v=wAg5JjKdKqg.

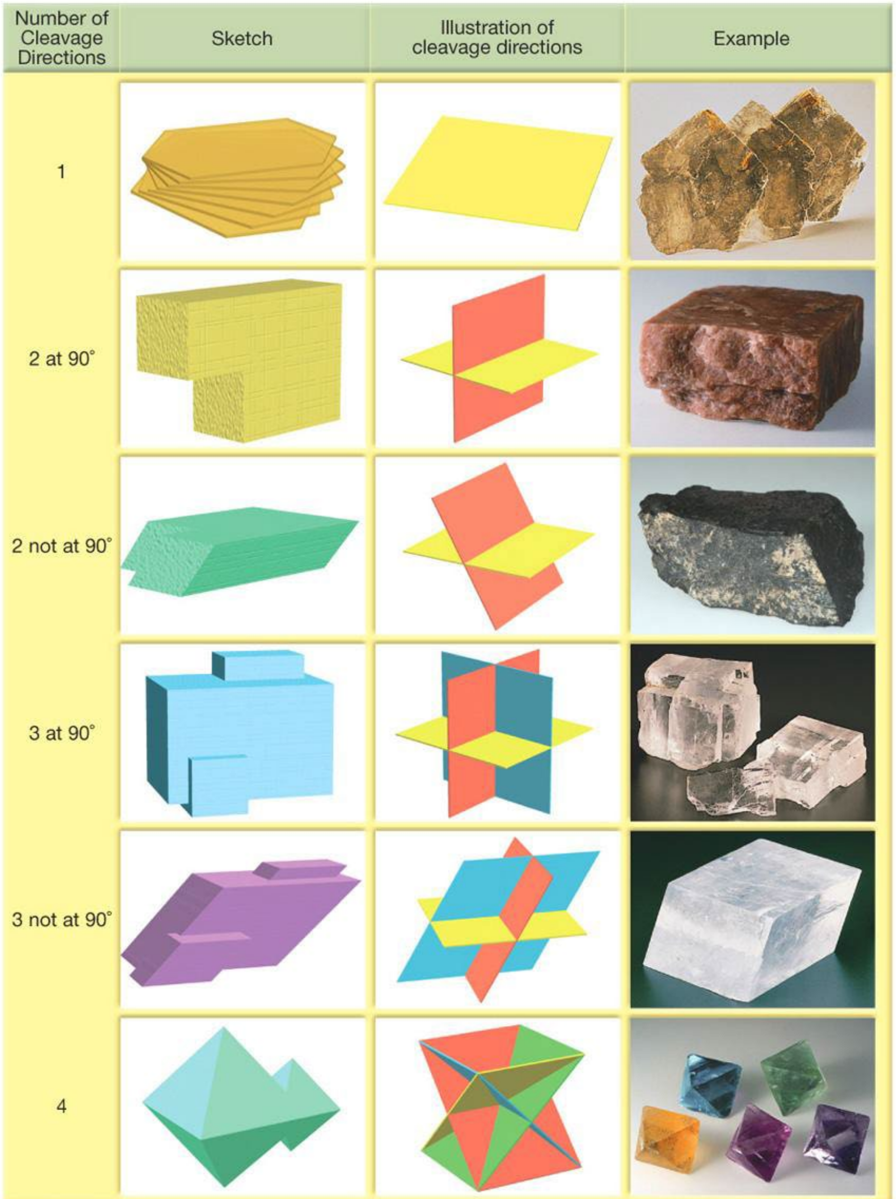


Image from: https://sternberg.fhsu.edu/research-collections/geology/mineral-classification-page.html

Lustre

Lustre is the overall sheen of a mineral's surface. Very simply, lustre can be grouped into metallic lustre – looking like polished metal, or non-metallic lustre – which is further broken down into other types such as vitreous (glassy), earthy, dull, silky, resinous, pearly, etc. Some typical lustre names are listed below:

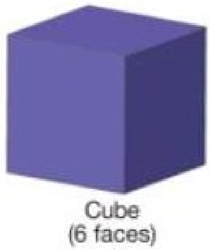
- Metallic → Pyrite
- Vitreous (non-metallic) → Quartz
- Earthy (non-metallic) → Hematite
- Pearly (non-metallic) → Talc

There are lots of free videos on YouTube demonstrating how to identify the lustre of a mineral. Two examples are https://www.youtube.com/watch?v=rkZOdng2oJk and https://www.youtube.com/watch?v=MuJN-H52mGM.

Crystal System

A crystal system is the shape that a mineral grows in, based on its internal chemical composition and crystal structure. Each crystal system is based on the angles and intersection of a 3-point axis. Some mineral shapes are listed below: Images modified from https://www.geologyin.com/2019/10/crystal-habits-and-forms.html

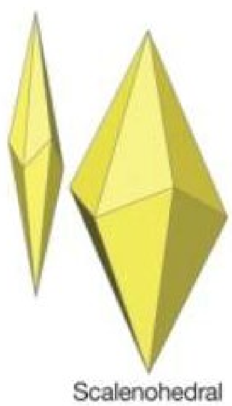
- Cube → Halite



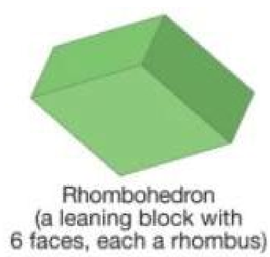
- Rhomb-dodecahedron → Garnet

- Pentagon-dodecahedron (Pyritohedron) →Pyrite

- Scalenohedron → Calcite



- Rhombohedron → Calcite



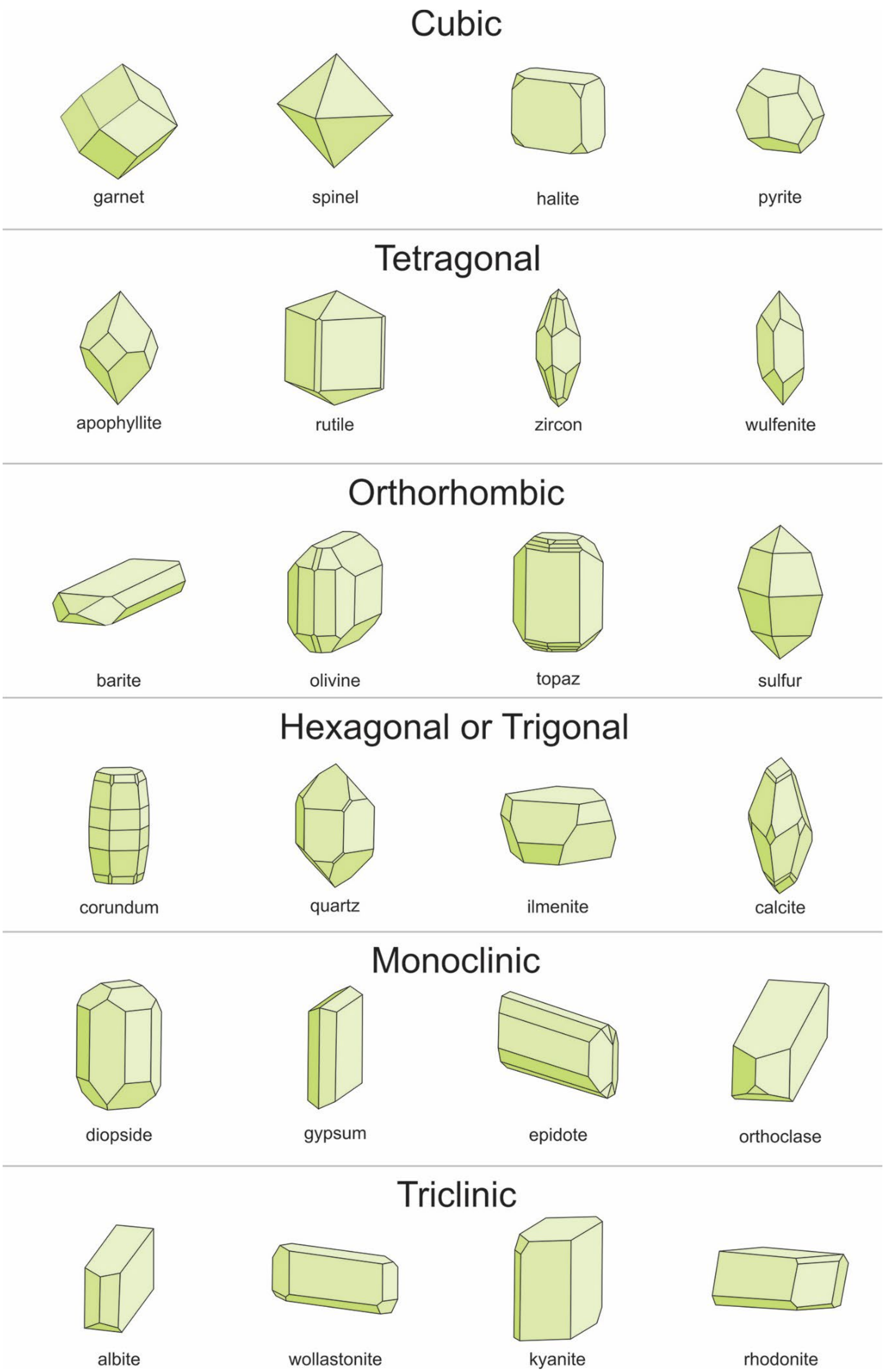


Image from: https://opengeology.org/Mineralogy/10-crystal-morphology-and-symmetry/

Example Mineral Identification

The section below is a step-by-step example of the process used to identify an unknown mineral specimen, known as "UKN" utilizing the properties discussed above.

LUSTRE:

- *UKN has a non-metallic lustre. This means that UKN is not the mineral graphite, hematite, magnetite, pyrite, chalcopyrite, sphalerite, galena or copper.*

HARDNESS:

- *UKN is scratched across a glass plate, and UKN does not make a scratch on the glass plate. We now know that UKN is <u>softer</u> than the glass plate, or softer than 5.5 on Moh's scale.*
- *We can then scratch UKN with a copper nail, and the copper nail does not scratch UKN. This means that UKN is <u>harder</u> than the copper nail, or 3 on Moh's scale.*
- *Therefore, UKN has a hardness between 3 and 5.5. We can use this information to compare to the known hardness of minerals in the below guidebook to narrow down the possible identity of UKN. Possible mineral identification for UKN is fluorite, malachite, celestite, azurite, apophyllite. To narrow this down, we must test other properties.*

COLOUR:

- *UKN is blue in colour. This narrows down our list of possible mineral identification for UKN to fluorite, celestite, azurite, and apophyllite.*

STREAK:

- *UKN is scratched along the surface of a porcelain streak plate. UKN does not appear to leave a streak. However, knowing that the hardness is less than 5.5, or in other words, UKN is softer than the streak plate, a streak should have been left behind. Upon closer inspection, you see that a white streak was left behind on the porcelain streak plate. This narrows down our list of possible mineral identification for UKN to fluorite, celestite, and apophyllite.*

CLEAVAGE/CRYSTAL SYSTEM:

- *UKN appears as octahedral crystals, but at first it is unknown if these specimens are exhibiting growth features (i.e. the mineral grew as octahedrons) or cleavage planes (i.e. the mineral was broken, resulting in this shape). From referring to your chart, you recall that the only mineral listed as having octahedral cleavage is fluorite.*

<u>Based on the above information, you are able to identify that UKN is the mineral fluorite!</u>

A free video demonstrating mineral identification strategies is available on YouTube, and the link is https://www.youtube.com/watch?v=YxpnvDAkczM.

Properties Used to Identify Rocks

Rocks are classified into 3 categories: igneous, sedimentary, and metamorphic.

Igneous Rocks

Igneous rocks are formed by the solidification and crystallization of molten rock, which originates at depth and rises towards the surface where it cools. They are classified by the minerals they contain and their grain size. The rate of cooling affects the grain size (mineral size) of the rock. If cooling is rapid the resulting rock will have small crystals not distinguishable to the naked eye, or may even be glassy (i.e. obsidian). Rocks that cooled quickly are known as extrusive or volcanic rocks, because the quick cooling is due to their extrusion on Earth's surface. The fine grain size is known as an aphanitic texture. Slow cooling of the molten rock results in a larger grain size (larger minerals) that are visible to the naked eye. Rocks that have cooled slowly are known as intrusive, or plutonic rocks, because their slow cooling occurs below the surface of Earth, in large magma chambers, known as plutons. The coarse-grained texture is known as a phaneritic texture.

The composition of igneous rocks, i.e. the minerals they contain, vary depending on the source of the magma from which they formed. Common minerals found in igneous rocks include quartz, feldspars, micas, pyroxenes, amphiboles, and olivine. These different compositions are divided into three main classes, mafic, intermediate, and felsic. Mafic rocks are igneous rocks that have a composition rich in magnesium (Mg) and iron (Fe) minerals. These minerals are primarily dark in colour (i.e. black and dark brown), such as pyroxene, olivine, hornblende and calcium-rich plagioclase feldspar (anorthite). Felsic rocks are igneous rocks that have a composition rich in feldspar and silica-rich minerals. These minerals are primarily light in colour (i.e. gray, pink, white), such as quartz and feldspar, specifically potassium feldspar and sodium-rich plagioclase feldspar (albite). Intermediate rocks are a mixture of both dark and light minerals, hence the name Intermediate. The image to the right shows the types of igneous rocks by their compositional and textural classification, and the minerals they contain.

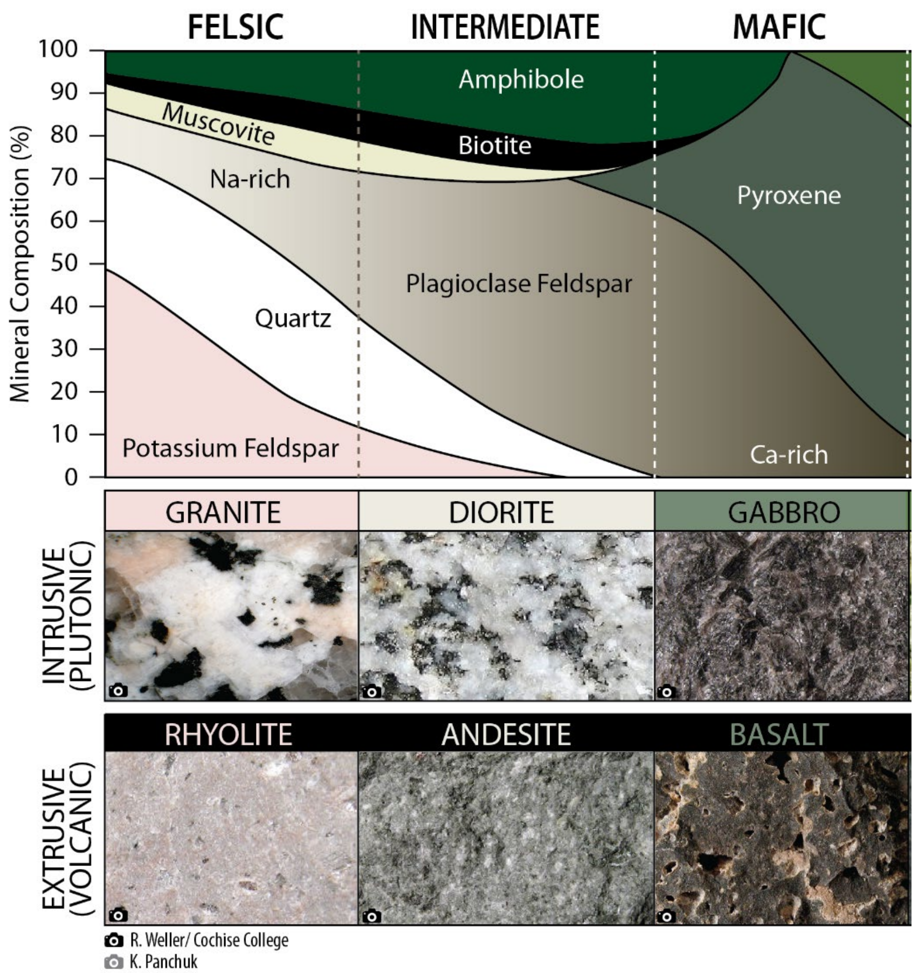


Image from https://openpress.usask.ca/physicalgeology/chapter/7-3-classification-of-igneous-rocks-2/

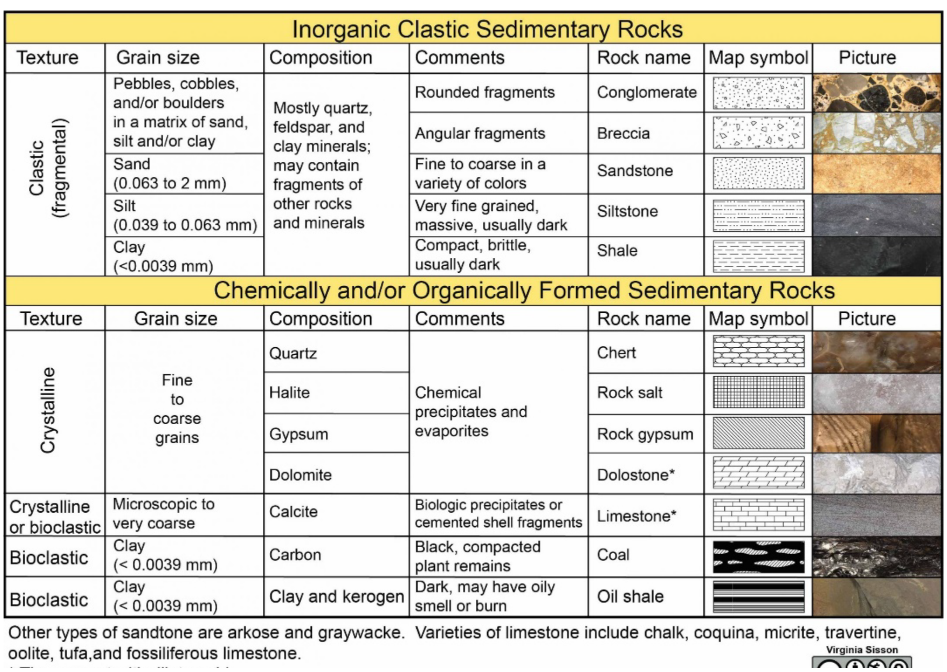
Some lava sources can have a very high content of water and dissolved gasses. As the bubbles escape, the lava becomes frothy, and the resulting rock contains large numbers of open pores and is called pumice (light in colour) or scoria (dark in colour). These rocks are extremely light and can even float on water due to their low density.

When lava flows pick up rock fragments, they can form what is called a volcanic breccia, because the resulting rock ends up being made of many clasts of other rock material, held together by the solidified lava.

Sedimentary Rocks

Generally, the classification of sedimentary rocks is broken into two broad categories – Clastic (detrital) sedimentary rocks, and chemical sedimentary rocks. Clastic sedimentary rocks are formed from solid particles of pre-existing rocks, or the remains of plants, animals, and organisms (called sediments) that accumulate on Earth's surface. If these sediments are buried, they become compacted and cemented (lithified), and this process of lithification forms sedimentary rocks. As more and more sediment accumulates over time, the weight and pressure from the overlying layers cause the sediments to compact and cement together. Chemical sedimentary rocks form by the precipitation of ions in solution. Most sedimentary rocks form by a combination of these processes, with sediments being held together by a chemical cement. An example of a purely chemical sedimentary rock is rock gypsum (alabaster) that forms from the evaporation of seawater, and the precipitation of gypsum.

Clastic sedimentary rocks are classified based on their grain size and composition, similar to igneous rocks. The grain size is determined by the rate of weathering of the sediments, and the composition is based on the source rock and degree of weathering. The below image shows examples of the grain size differences between different types of clastic sedimentary rocks. Please note that not all rocks in this diagram are possible options for the Geology Triathlon – please refer to the guidebook for the types of rocks that are possible for the event.



Inorganic Clastic Sedimentary Rocks						
Texture	Grain size	Composition	Comments	Rock name	Map symbol	Picture
Clastic (fragmental)	Pebbles, cobbles, and/or boulders in a matrix of sand, silt and/or clay	Mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks and minerals	Rounded fragments	Conglomerate		
			Angular fragments	Breccia		
	Sand (0.063 to 2 mm)		Fine to coarse in a variety of colors	Sandstone		
	Silt (0.039 to 0.063 mm)		Very fine grained, massive, usually dark	Siltstone		
	Clay (<0.0039 mm)		Compact, brittle, usually dark	Shale		
Chemically and/or Organically Formed Sedimentary Rocks						
Texture	Grain size	Composition	Comments	Rock name	Map symbol	Picture
Crystalline	Fine to coarse grains	Quartz	Chemical precipitates and evaporites	Chert		
		Halite		Rock salt		
		Gypsum		Rock gypsum		
		Dolomite		Dolostone*		
Crystalline or bioclastic	Microscopic to very coarse	Calcite	Biologic precipitates or cemented shell fragments	Limestone*		
Bioclastic	Clay (< 0.0039 mm)	Carbon	Black, compacted plant remains	Coal		
Bioclastic	Clay (< 0.0039 mm)	Clay and kerogen	Dark, may have oily smell or burn	Oil shale		

Other types of sandtone are arkose and graywacke. Varieties of limestone include chalk, coquina, micrite, travertine, oolite, tufa,and fossiliferous limestone.

Image from https://uhlibraries.pressbooks.pub/physicalgeologylab/chapter/chapter-6-sedimentary-rocks/

Sedimentary rocks often contain important clues about Earth's history, as they can preserve fossils, provide insights into past environments, and record geological processes. They are also valuable resources as they often contain deposits of coal, oil, and natural gas.

Metamorphic Rocks

Metamorphic rocks form when igneous, sedimentary, or pre-existing metamorphic rocks are subjected to high temperature, pressure or hot mineral-rich fluids over time, and transformed into a new rock. The time scale of these processes is thousands to millions of years. The original composition of the rock, and temperature and pressure of metamorphism, determine the resulting mineral composition, texture, and structural features of the newly formed metamorphic rock.

Metamorphic rocks are generally classified into two main subgroups, foliated or non-foliated. Foliation, or banding/layering of the minerals in the rock, is typically formed perpendicular to the direction of pressure (stress) exerted on the rock. Non-foliated rocks do not have this banding and are typically made up of one main type of mineral. An example of a non-foliated metamorphic rock is a quartzite, which is formed by the metamorphism of sandstone (protolith), which is made up predominantly of the mineral quartz. Quartzite has a larger grain size than the precursor sedimentary sandstone and has a sugary texture and less of a sandy texture. An example of a highly foliated metamorphic rock is a gneiss. The protolith of a gneiss is either a shale or an igneous rock, that has undergone extreme heat and pressure. Due to this heat and pressure, a gneiss is made up of alternating bands of light and dark coloured minerals, and this extreme banding is known as gneissic banding. An example of a foliated metamorphic rock that has undergone a lower grade of metamorphism is a phyllite. Phyllites still show foliation, but on a microscopic scale. In hand sample, this is shown as a satin-like lustre/sheen in one direction. The diagram to the right shows the difference between types of metamorphic rocks. All the rocks shown are possible in the Geology Triathlon except for Hornfels.

Metamorphic rocks provide valuable information about the Earth's geological history, as they can indicate past tectonic activity and the conditions under which they formed.

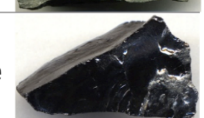
TEXTURE	CHARACTERISTICS	PROTOLITH	METAMORPHIC ROCK	
NON FOLIATED	Blocky grains of quartz (hardness 7).	Sandstone or Siltstone	Quartzite	
	Blocky grains of calcite (hardness 3). Fizzes with dilute HCl.	Limestone	Marble	
	Fine-grained, various colours.	Shale or Basalt	Hornfels	
	Soft (hardness ~3), glossy, and black, with low specific gravity (~1.4).	Bituminous coal	Anthracite	
FOLIATED (INCREASING PRESSURE & TEMPERATURE)	Alternating bands of light- and dark-coloured minerals (dark minerals are usually biotite or amphibole), called gneissic banding.	Shale or Igneous Rock	Gneiss	
	Contains shiny muscovite (light) or biotite (dark) micas. May also have quartz, talc, garnet (red arrow), amphibole. Schistose pattern of foliation.	Shale	Schist	
	Fine-grained rock with the grains only visible as a satin sheen. Similar to slate, but with a satin lustre and may have wrinkled cleavage.	Shale	Phyllite	
	Very fine-grained rock, tends to split in parallel fragments (known as slaty cleavage).	Shale	Slate	

Image from https://pressbooks.bccampus.ca/geolmanual/chapter/overview-of-metamorphic-rocks/

Fossils

Fossils are the remains or impression of a prehistoric plant, animal, or organism that has been preserved in rock. Most organisms become fossilized by being buried in sediment shortly after death, so that they leave an impression in the sediments before decomposing. Organisms without skeletons or shells are seldom fossilized due to their rapid rate of decomposition. The below image shows how some fossils can be preserved. Fossils are identified based on their shape, morphology, and common features. The main types of fossils that are potentially going to be provided as part of the Geology Triathlon are described in the guidebook on the following pages. Please review these prior to taking part in the event.

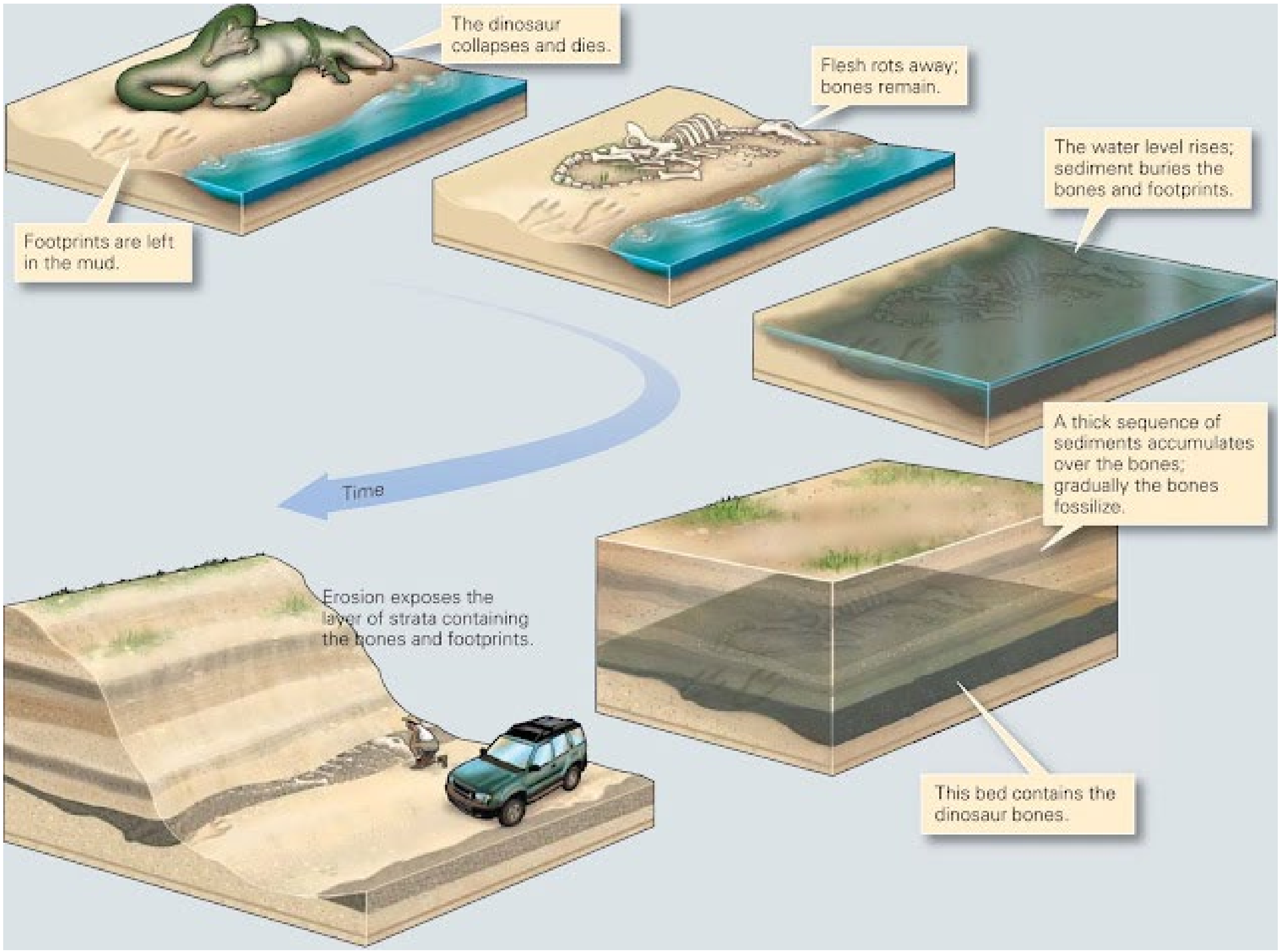


Image from https://geologylearn.blogspot.com/2016/03/fossilization.html

Geology Triathlon Guidebook

Minerals

The below table shows the minerals that could be provided in the Geology Triathlon, and their properties, with key properties underlined.

1. Talc - $Mg_3Si_4O_{10}(OH)_2$ Colour: white, grey, pale green, pale pink Hardness: 1 Streak: white Cleavage: basal perfect Lustre: greasy to dull, pearly, soapy feel System: monoclinic	 Source: https://www.britannica.com/science/talc
2. Gypsum (selenite) - $CaSO_4 \cdot 2H_2O$ Colour: colourless to white; often tinged other hues due to impurities; yellow, tan, blue, pink, dark brown, reddish brown, or gray Hardness: 2 Streak: white Cleavage: 3 directions, rhombohedral Lustre: vitreous to pearly System: monoclinic	 Source: https://www.minerals.net/mineral/gypsum.aspx
3. Calcite - $CaCO_3$ Colour: any colour Hardness: 3 Cleavage: perfect rhombohedral Lustre: vitreous to pearly on cleavage surfaces Streak: white System: rhombohedral Other: effervesces in HCl Other: Clear varieties show double refraction of images under the specimen	 Source: https://www.mineralauctions.com/items/large-calcite-iceland-spar-cleavage-81303
4. Fluorite - CaF_2 Colour: green, purple, blue, yellow, etc. Hardness: 4 Streak: white Cleavage: four directions – octahedral Lustre: vitreous System: isometric	 Source: https://www.deepearthtreasures.com/products/madagascan-green-fluorite-natural-specimen-32mm-22g

5. Quartz - SiO_2 Colour: any colour Hardness: 7 Streak: none Fracture: conchoidal Lustre: vitreous System: trigonal Varieties: amethyst (purple), smoky (black-brown), rose (pink), citrine (yellow)	 Source: https://www.minerals.net/mineral/quartz.aspx  Source: https://canada.michaels.com/en/rough-rose-quartz-by-ashland/10558676.html
6. Microcline - $KAlSi_3O_8$ Colour: usually white or pink, can be blue or green (amazonite) Hardness: 6 Streak: white Cleavage: 2 directions of cleavage at 90° Lustre: vitreous System: triclinic Other: will show exsolution	 Source: https://www.sandatlas.org/microcline/
7. Albite - $NaAlSi_3O_8$ Colour: white or grey or brown (iridescent albite is called peristerite or moonstone) Hardness: 6-6.5 Streak: white Cleavage: 2 directions at ~90° Lustre: vitreous, typically pearly on cleavages System: triclinic	 Source: https://www.boreal.com/store/product/8865926/albite
8. Hornblende - $(Ca,Na)_{2\text{-}3}(Mg,Fe,Al)_5Si_6(Si,Al)_2O_{22}(OH)_2$ Colour: generally black or dark green Hardness: 5-6 Streak: pale grey, grey-white, white Cleavage: 56° / 124° Lustre: vitreous to dull System: monoclinic	 Source: https://www.eiscolabs.com/products/esng0019

9. Augite - $(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$ Colour: dark green to black Hardness: 5.5-6 Streak: greenish white Cleavage: 2 directions at 90° Lustre: vitreous, resinous to dull System: monoclinic	 Source: https://geology.com/minerals/augite.shtml
10. Muscovite - $KAl_2Si_3AlO_{10}(OH)_2$ Colour: colourless/transparent to pale greenish Hardness: 2-2.5 Streak: white Cleavage: basal Lustre: vitreous, silky, or pearly System: monoclinic	 Source: http://nevada-outback-gems.com/mineral_information/Mica_muscovite_mineral_info.htm
11. Biotite - $K(Mg,Fe)_3Si_3AlO_{10}(OH)_2$ Colour: black Hardness: 2-3 Streak: white Cleavage: basal Lustre: vitreous System: monoclinic	 Source: https://geologyscience.com/minerals/biotite/
12. Olivine - $(Mg,Fe)_2SiO_4$ Colour: green Hardness: 6.5-7 Streak: colourless or white Cleavage: conchoidal Lustre: glassy System: orthorhombic	 Source: https://www.geologyin.com/2016/12/study-of-olivine-provides-new-data-for.html
13. Graphite - C Colour: steel grey to black Hardness: 1-2 Streak: grey (like a pencil) Cleavage: basal Lustre: greasy, metallic to dull System: hexagonal Other: is what pencil lead is made of	 Source: https://geologyscience.com/minerals/graphite/

14. Halite - NaCl Colour: colourless, white, greyish, blueish, yellowish, red, etc. Hardness: 2.5 Streak: white Cleavage: cubic, perfect, 3 at 90^{o}, conchoidal fracture Lustre: vitreous System: isometric Other: tastes salty, water soluble, slippery	 Source: https://www.le-comptoir-geologique.com/halite-en-halite-ref-z01-09.html
15. Hematite - Fe_2O_3 Colour: red or steel grey (specular hematite) Hardness: 5-6 Streak: red-brown Cleavage: none, may show partings Lustre: earthy-metallic System: hexagonal	 Source: https://geology.com/minerals/hematite.shtml
16. Magnetite - Fe_3O_4 Colour: iron black Hardness: 5.5-6 Streak: iron black Cleavage: none, may show partings Lustre: metallic System: isometric Other: very magnetic	 Source: https://geology.com/minerals/magnetite.shtml
17. Pyrite - FeS_2 Colour: pale brass yellow; lack of tarnish vs. chalcopyrite Hardness: 6-6.5 Streak: greenish-black to brownish-black Cleavage: conchoidal to uneven Lustre: metallic System: isometric	 Source: https://stock.adobe.com/ca/search?k=pyrite
18. Chalcopyrite - $CuFeS_2$ Colour: brass yellow, often with slightly iridescent tarnish Hardness: 3.5-4 Streak: greenish black Cleavage: poor – not well defined Lustre: metallic System: tetragonal	 Source: https://geology.com/minerals/chalcopyrite.shtml

19. Sphalerite - ZnS Colour: brown to yellowish, reddish, black Hardness: 3.5-4 Streak: brownish white, pale yellow Cleavage: dodecahedral Lustre: non-metallic to resinous, to sub-metallic in opaque specimens System: isometric	 Source: https://www.virtualmicroscope.org/content/sphalerite
20. Galena - PbS Colour: lead-grey; opaque Hardness: 2.5 Streak: lead-grey Cleavage: cubic Lustre: bright metallic System: isometric, perfect Other: very heavy (Specific Gravity = 7.6)	 Source: https://www.britannica.com/science/galena-mineral
21. Malachite - $Cu_2CO_3(OH)_2$ Colour: bright green to blackish green Hardness: 3.5-4 Streak: light green Cleavage: Perfect in one direction, conchoidal fracture Lustre: adamantine, vitreous, silky, dull, earthy System: monoclinic	 Source: https://en.wikipedia.org/wiki/Malachite
22. Copper - Cu Colour: copper-red to brown, tarnishes green Hardness: 3 Streak: copper-red Fracture: Hackly Lustre: metallic System: isometric	 Source: https://en.wikipedia.org/wiki/Copper
23. Sodalite – $Na_8Al_6Si_6O_{24}Cl_2$ Colour: royal blue, white veining common Hardness: 5.5-6 Streak: white Fracture: Conchoidal Lustre: dull, vitreous, greasy System: cubic	 Source: https://www.mindat.org/min-3701.html

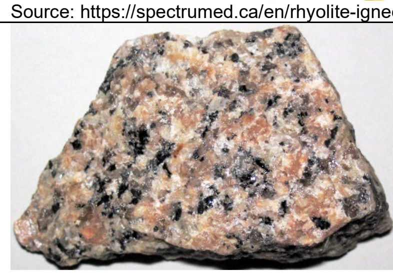
24. Celestite – $SrSO_4$ Colour: white, gray, pale blue Hardness: 3-3.5 Streak: white Cleavage: Three directions – splits into thin, flat fragments Lustre: vitreous, pearly System: orthorhombic Other: Tends to crystallize as geodes	 Source: https://www.madagascandirect.com/article/1/Celestite/
25. Lepidolite – $K(Li,Al)_3(Al,Si,Rb)_4O_{10}(F,OH)_2$ Colour: pink, light purple, purple, rose-red, violet-gray, yellowish, white, colourless Hardness: 2.5-3 Streak: white Cleavage: basal Lustre: vitreous, pearly System: monoclinic	 Source: https://geology.com/minerals/lepidolite.shtml
26. Azurite – $Cu_3(CO_3)_2$ Colour: azure-blue, dark to pale blue Hardness: 3.5-4 Streak: light blue Cleavage: perfect in one direction, conchoidal fracture Lustre: vitreous System: monoclinic	 Source: https://en.wikipedia.org/wiki/Azurite
27. Garnet - $A_3B_2(SiO_4)_3$ where A is a divalent cation (Fe^{2+}, Ca^{2+}, Mg^{2+}, Mn^{2+}) and B is a trivalent cation (Fe^{3+}, Al^{3+}, Cr^{3+}). Colour: any colour Hardness: 6.5-7.5 Streak: white Fracture: conchoidal Lustre: vitreous System: isometric (rhomb-dodecahedron) Varieties: almandine, grossular, uvarovite, pyrope	 Source: https://e-rocks.com/item/jwt199949/garnet-var-almandine  Source: https://www.abijoux.com/grossular-garnet-19-06-ct.htm

28. Apatite – $Ca_5(PO_4)$ Colour: transparent to translucent, usually green, less often colourless, yellow, blue to violet, pink, brown Hardness: 5 Streak: white Fracture: conchoidal Lustre: vitreous System: hexagonal	 Source: https://www.britannica.com/science/apatite
29. Topaz – $Al_2SiO_4(F,OH)_2$ Colour: colourless, white, blue, brown, orange, gray, yellow, yellowish brown, green, pink, reddish pink, red Hardness: 8 Streak: none Cleavage: perfect basal cleavage Lustre: vitreous System: orthorhombic	 Source: https://monolisadesigns.com/blogs/gemstones/the-history-behind-a-topaz-gemstone
30. Apophyllite - $Ca_4KFSi_8O_{20} \cdot 8H_2O$ Colour: white, colourless; also blue, green, brown, yellow, pink, violet Hardness: 4.5-5 Streak: white Cleavage: perfect in one direction Lustre: vitreous, pearly System: tetragonal	 Source: https://en.wikipedia.org/wiki/Apophyllite
31. Epidote - $Al_2Ca_2FeH_2O_{13}Si_3$ Colour: pistachio-green, yellow-green, greenish black, brownish-green, green, black Hardness: 6-7 Streak: greyish white Cleavage: perfect in one direction Lustre: vitreous to resinous System: monoclinic	 Source: https://www.britannica.com/science/epidote
32. Corundum - Al_2O_3 Colour: colourless, gray, golden-brown, brown, purple, pink, red, orange, yellow, green, blue, violet Hardness: 9 Streak: none Fracture: conchoidal Lustre: adamantine to vitreous System: trigonal (hexagonal prism) Varieties: ruby (red), sapphire (any colour besides red)	 Source: https://geology.com/minerals/corundum.shtml  Source: https://stock.adobe.com/ch_fr/search?k=sapphire+raw&asset_id=298633930

33. Labradorite – $(Ca,Na)(Al,Si)_4O_8$ Colour: grey-white, greenish, blue, yellow Hardness: 6-6.5 Streak: white Cleavage: 2 at 90^o Lustre: vitreous to pearly System: triclinic <u>Other: displays iridescent blue/green flashes</u>	  Source: https://www.mindat.org/min-246.html https://www.mindat.org/photo-411944.html
34. Anorthite - $CaAl_2Si_2O_8$ Colour: typically gray Hardness: 6 Streak: white <u>Cleavage: 2 at 90^o</u> Lustre: vitreous System: triclinic	 Source:https://www.weinrichmineralsinc.com/products/anorthite-4271506.php

Rocks

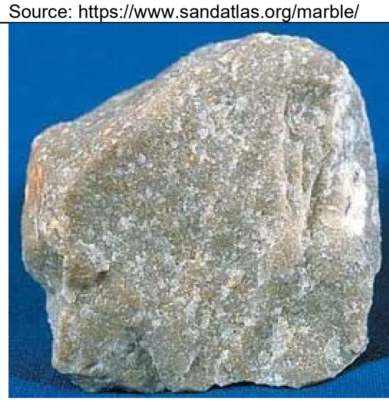
The below table shows the rocks that could be provided in the Geology Triathlon, and their properties.

1. Obsidian – a natural glass that forms from rapidly cooled lava. Primarily composed of silica-rich materials, such as silicon dioxide (SiO_2) or quartz. Typically is dark in colour, often black or dark brown, but it can also occur in shades of green, red, or gray.	 Source: https://www.hilltribeontario.com/products/black-obsidian-natural-chunks
2. Rhyolite – a fine-grained igneous rock that is composed mainly of quartz, feldspar, and lesser amounts of biotite, amphibole, or pyroxene minerals. Can exhibit a range of colours, including light gray, pink, brown, or green.	 Source: https://spectrumed.ca/en/rhyolite-igneous-rock-1
3. Granite – coarse-grained igneous rock that is composed mainly of quartz, feldspar, and mica. Typical colours of mineral grains are pink, black, white and gray.	 Source: https://commons.wikimedia.org/wiki/File:Granite_47_%2849201189712%29.jpg
4. Diorite – coarse-grained igneous rock primarily composed of plagioclase feldspar, biotite or hornblende, and small amounts of quartz. Characterized by its speckled salt-and-pepper texture (commonly referred to as a dalmatian rock, like the spotted dogs).	 Source: https://geology.com/rocks/diorite.shtml
5. Basalt – fine-grained igneous rock composed mainly of dark minerals like pyroxene, plagioclase feldspar, and sometimes olivine.	 Source: https://en.wikipedia.org/wiki/Basalt

6. Gabbro – coarse-grained igneous rock composed mainly of dark-coloured minerals, particularly pyroxene and plagioclase feldspar. Typically dark green to black in colour.	 Source: https://geologyscience.com/rocks/igneous-rocks/intrusive-igneous-rocks/gabbro/
7. Volcanic Breccia - composed of angular to subangular rock fragments larger than 2 mm in diameter. Colour can vary depending on the composition of the fragments and minerals present.	 Source: https://rocksminerals.flexiblelearning.auckland.ac.nz/rocks/breccia.html
8. Pumice - lightweight, porous volcanic rock formed during explosive volcanic eruptions. Contains numerous cavities/gas bubbles known as vesicles. Colour can vary from white or light gray to cream, beige, or pale pink. Will typically float on water due to its extremely low density.	 Source: https://geology.com/rocks/pumice.shtml
9. Tuff - composed of consolidated volcanic ash and may contain various-sized fragments of pumice, rock, and crystals. Colour can vary depending on the minerals present in the volcanic ash, ranging from light gray and beige to pink, brown, or even greenish hues.	 Source: https://geology.com/rocks/tuff.shtml
10. Andesite - composed of plagioclase feldspar, which gives it a light-gray to gray colour. Also contains varying amounts of other minerals such as amphibole, pyroxene, and biotite. Has a fine-grained texture and sometimes is porphyritic (contains larger grained minerals in a fine-grained groundmass).	 Source: https://geology.com/rocks/andesite.shtml

11. Limestone - composed primarily of the mineral calcite. Formed through the accumulation and lithification of marine organisms, like coral, shells, and microorganisms, as well as from the precipitation of calcium carbonate from water.	 Source: https://geology.com/rocks/limestone.shtml
12. Chalk – Composed completely of the mineral calcite. Is soft, fine-grained, porous, and easily crumbled. Typically white or light gray in colour and has a powdery or earthy texture. Previously used as chalk for chalkboards before synthetic chalk became widely used.	 Source: https://geology.com/rocks/chalk.shtml
13. Coquina - composed of fragmented shell and coral debris. Colour ranges from white, beige, and yellow to gray or even pink, depending on the specific types of shells present. Texture is coarse due to the larger shell fragments and has a grainy or sandy feel.	 Source: https://geologyhub.com/coquina-limestone-sedimentary-rock/
14. Rock Gypsum (Alabaster) - primarily composed of the mineral gypsum (calcium sulfate dihydrate, $CaSO_4 \cdot 2H_2O$). Has a fibrous or granular texture and can exhibit a range of colours, including white, gray, pink, or even translucent.	 Source: https://csmgeo.csm.jmu.edu/geollab/fichter/minerals/minerals/gypsumala.html
15. Conglomerate - composed of rounded to sub-rounded rock fragments or pebbles that are held together by a cementing material, such as silica, calcium carbonate, or iron oxide. Can have various colours depending on the composition of the rock fragments and cementing material. Often has a coarse-grained texture with distinct, rounded clasts.	 Source: https://www.minerals-kingdom.com/stones-virtues/conglomerate/

16. Sandstone - composed of sand-sized grains of mineral, rock, or organic material. Typically composed of minerals like quartz, feldspar, mica, and various rock fragments. Colours range from white and yellow to red, brown, and even green. Will feel gritty, like sand or sandpaper, on your fingers.	 Source: https://www.sandatlas.org/sandstone/
17. Siltstone - composed of fine-grained particles called silt (0.002 - 0.06 mm diameter). Characterized by fine-grained texture and smooth appearance. Often gray, brown, or reddish in colour, depending on the mineral composition and impurities present.	 Source: https://geology.com/rocks/siltstone.shtml
18. Shale - characterized by fine-grained composition and ability to split into thin layers. Often smooth texture and dull appearance. Primarily composed of clay-sized particles along with other fine-grained minerals like quartz, feldspar, and mica. Will appear earthy in texture.	 Source: https://www.thoughtco.com/shale-rock-4165848
19. Chert - composed of microcrystalline or cryptocrystalline quartz. Often has a dull or waxy lustre and can exhibit a range of colours, including white, gray, brown, black, or red. Known for its hardness (7) and conchoidal fracture.	 Source: https://www.sandatlas.org/chert/

20. Marble - primarily composed of recrystallized carbonate minerals, typically calcite or dolomite. Forms through the metamorphism of limestone or dolostone. Colours include white, gray, black, green, pink, and various shades in between. Will have larger grain size than limestone due to metamorphism.	 Source: https://www.sandatlas.org/marble/
21. Quartzite - forms from the metamorphism of quartz-rich sandstone. Can be found in shades of white, gray, yellow, pink, red, brown, and even green. Has a granular and crystalline texture, with interlocking quartz grains that exhibit a sugary appearance.	 Source: https://www.britannica.com/science/quartzite
22. Slate - forms from the metamorphism of shale. Characterized by its distinct foliation allowing it to be easily split into thin, flat sheets. Colour of slate can vary, with common shades including gray, black, blue, green, and purple. Uses for slate include chalk boards, pool tables, and other surfaces that are required to be perfectly flat.	 Source: https://mineralseducationcoalition.org/minerals-database/slate/
23. Phyllite - forms from the metamorphism of shale or slate. Characterized by its fine-grained texture, parallel alignment of mineral grains, and a distinctive sheen or luster due to very fine-grained micas present in the rock. Colour can vary but is commonly gray, green, or brown.	 Source: https://geologyscience.com/rocks/phyllite/
24. Gneiss - derived from various parent rocks (granite, shale, sandstone, etc.). During metamorphism, minerals within the rocks recrystallize and align into alternating light-colored and dark-colored layers. Light-colored layers are primarily composed of quartz and feldspar, and dark-colored layers consist of biotite, amphibole, or mica.	 Source: https://rockhoundresource.com/gneiss/

25. Coal - formed from the remains of plants that lived and accumulated in swampy environments millions of years ago. Dark black or black-brown color and a relatively smooth texture. Typically very lightweight.	 Source: https://www.britannica.com/science/anthracite
26. Mica-Garnet Schist - prominent minerals are mica and garnet. Colour can vary depending on the mineral content, with shades of gray, brown, or green being common. Often found in regions that have undergone significant mountain-building processes or regions affected by regional metamorphism. Will be very shimmery and sparkly, due to abundance of oriented micas.	 Source: https://www.flickr.com/photos/jsjgeology/16735443408

Fossils

The below table shows the fossils that could be provided in the Geology Triathlon, and their properties. Specimens provided during the triathlon may not be complete - they may only be partial specimens (e.g a trilobite head). However, they will be large enough that identification is possible.

<table>
<tr>
<td>1. Trilobites
Trilobites are marine arthropods that thrived in the Cambrian period (541 million years ago) and went extinct at the end of the Permian period (251 million years ago). Trilobites would eat worms or other invertebrates, scavenge for food on the ocean floor, or filter feed. Trilobites were the first in the animal kingdom to develop complex eyes. They are divided into three distinctly identifiable lobes, hence the name tri-lob-ites.</td>
<td>
Source(left): https://oumnh.ox.ac.uk/learn-trilobite-wall-1
Source (right): https://www.britannica.com/animal/trilobite</td>
</tr>
<tr>
<td>2. Brachiopods
Brachiopods are marine animals that have hard "valves" on their upper and lower surfaces, which can be open for feeding or closed for protection. Brachiopods first appeared in the Cambrian period (541 million years ago) and reached their highest diversity in the Devonian period (~400 million years ago). Brachiopods still exist today in very cold water, in polar regions, or in the deep sea and are rarely seen.</td>
<td>
Source: https://www.nhm.ac.uk/our-science/collections/palaeontology-collections/brachiopod-collection.html</td>
</tr>
<tr>
<td>3. Corals
Corals are marine invertebrates and are related to jellyfish and sea anemones. Rugose coral, also called horn coral, are an extinct form of solitary and colonial corals. They were abundant in Middle Ordovician - Late Permian seas. Tabulate corals are also an extinct form of coral. They are usually form colonies of individual hexagonal cells defined by a skeleton of calcite, looking somewhat like a honeycomb.</td>
<td>

Source: https://geoscienceinfo.com/bob-odonnell-fossils-at-hungry-hollow/


Source: https://pressbooks.bccampus.ca/earthhistorylab/chapter/fossils-of-the-paleozoic/</td>
</tr>
</table>

4. Gastropods Gastropods, commonly referred to as snails, are a class of invertebrates under the phylum of Molluscs. Their shells typically coil vertically about an axis, compared to horizontally like ammonites.	 Source: https://www.bgs.ac.uk/discovering-geology/fossils-and-geological-time/gastropods/
5. Bivalves Bivalves are marine and freshwater molluscs that have laterally compressed bodies enclosed by a shell consisting of two hinged parts. By the middle of the Paleozoic (400 million years ago) bivalves were among the most abundant filter feeders in the ocean, and over 12,000 fossil species are recognized. Bivalves come in many shapes and sizes, ranging from 0.52 mm to 1,200 mm.	 Source: https://ucmp.berkeley.edu/taxa/inverts/mollusca/bivalvia.php
6. Ammonites Ammonites were present at the beginning of the Jurassic period (201 million years ago) and went extinct at the end of the Cretaceous period (66 million years ago), around the same time the dinosaurs went extinct. Ammonites range in size from 20 mm to over 2 m in diameter, depending on the species. As ammonites evolved very rapidly and are found worldwide, they can be used to date rocks to an interval of 200,000 years (very precise in terms of geology).	 Source: https://www.nationalgeographic.com/animals/facts/ammonites