UNIVERSITY OF LIMERICK
OLLSCOIL LUIMNIGH

Scoil na Staire agus na Tíreolaíochta
School of History and Geography

GY4051

Earth Science and Society

Laboratory Workbook 2024/5

Earth Science and Society Laboratory Workbook

Watching and listening to lectures is a useful part of learning – but it's one thing seeing photos on a screen, and a different thing completely to hold something in your hand and see it with your own eyes. That's why this module has a strong laboratory component.

In these labs, you'll examine 20 different rocks and 9 different sediments, with additional supporting specimens you can examine but don't have to fully describe. You'll be asked to observe particular features, answer questions, and think about their relevance to society.

The intention of the labs is not to turn you into a geologist, or an expert on rock identification. The intention is that by seeing things with your own eyes, and working things out for yourself, the content you're learning in the lectures will change from just being words to remember to actually having real meaning.

Laboratory 1: Igneous Rocks

In the Volcanoes lecture, we discuss how magma is formed, and the different varieties of volcanoes, igneous intrusions, and landforms which result. These different varieties of volcanoes and intrusions produce characteristically different *igneous* rocks. That's what this lab aims to explore.

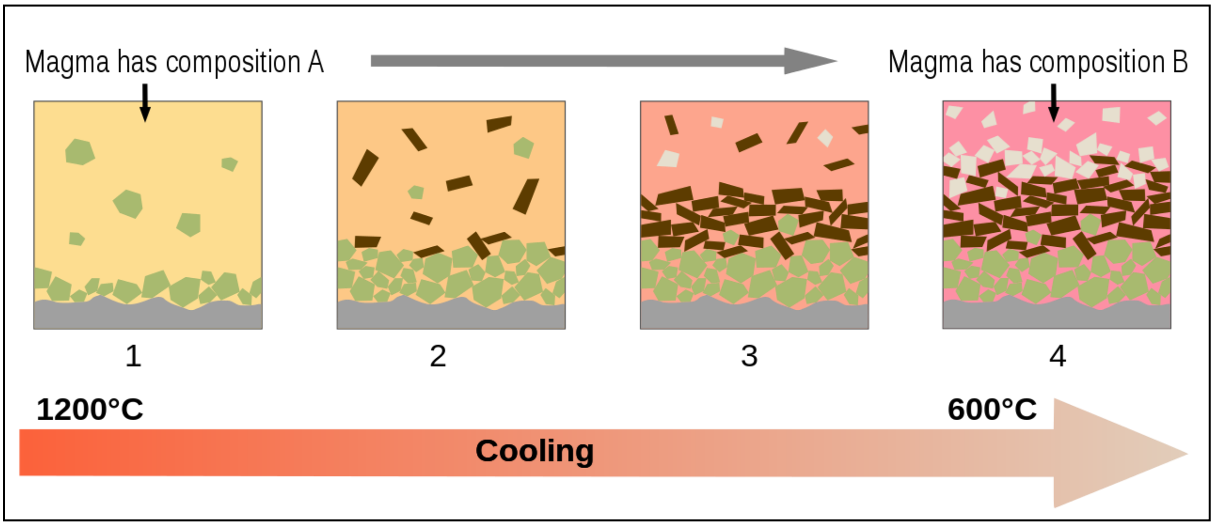
When looking at igneous rocks, there are two properties which are particularly important. These are the composition or chemistry of the rock; and the texture of the rock. Both of these properties can tell us very important details about how the rocks were formed.

Composition

In the lecture, I made particular mention of basalt. Basalt is a rock produced from basic magma. Basic magma with a basaltic composition is what is produced at mid-ocean ridges by partial melting of the mantle. At this stage, you can think of basic magma as the 'normal' or 'default' magma.

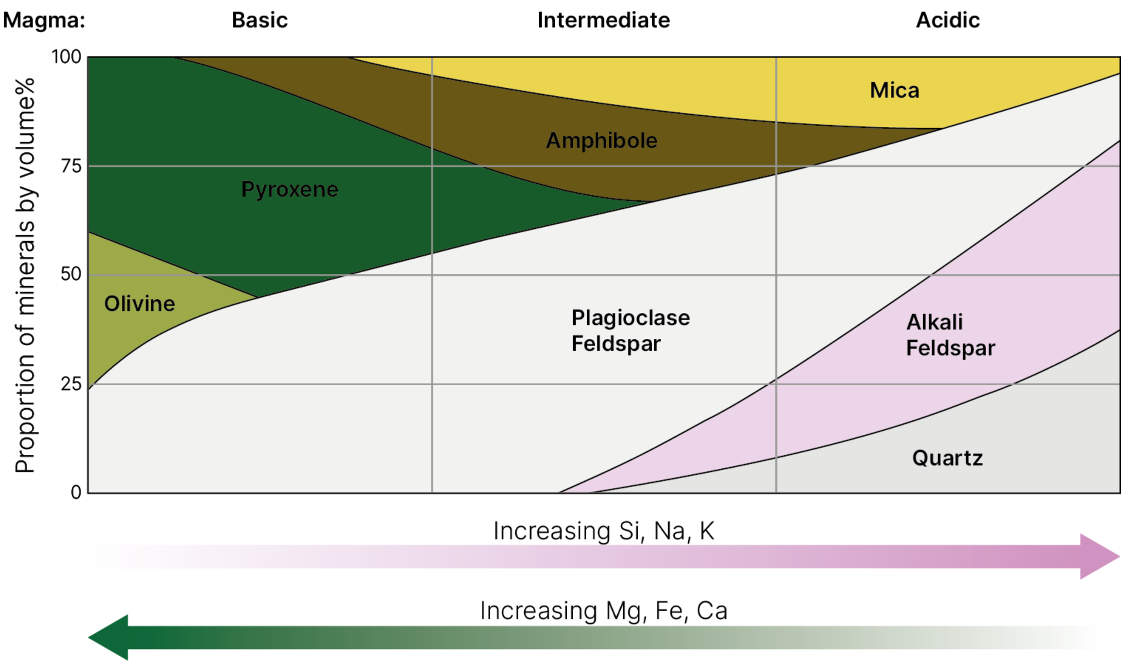
As it sits in a magma chamber, however, that magma can (and often does) change. Basic magma is hot when it forms – up to 1300^{0}C; often hot enough to melt the rocks surrounding the magma chamber. From that temperature, it will cool until it forms solid rock. As it cools, minerals will crystallise, and fall to the bottom of the magma chamber.

Importantly, the minerals that form don't have the same average composition as the magma itself. The first minerals that crystallise will be ones which contain elements like iron and magnesium – you can think of it as these prefer to be in a mineral over being in a liquid magma. So as these iron-rich and magnesium-rich minerals crystallise, and fall to the bottom, the magma has less and less iron and magnesium – and proportionately more of the elements which don't mind being part of a liquid magma, like sodium, potassium, aluminium, and silicon. This is called fractional crystallisation.

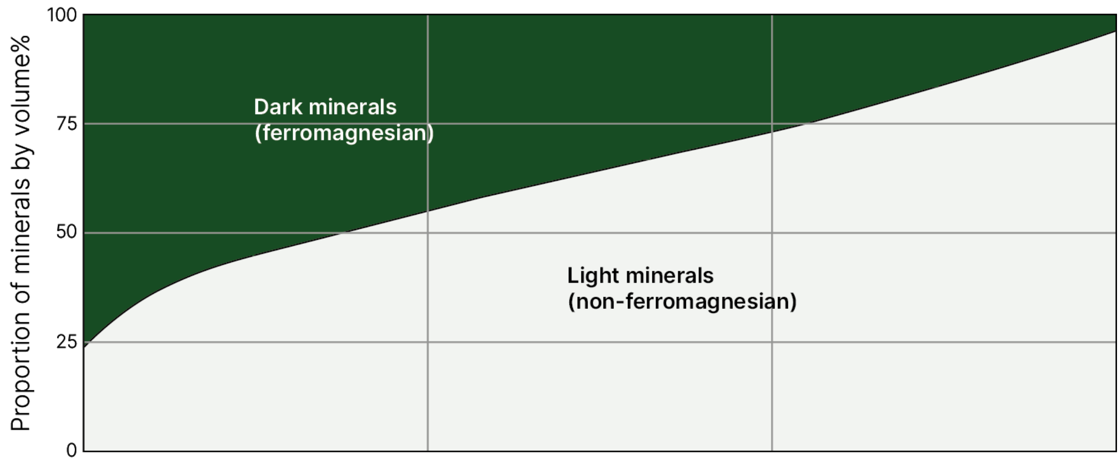


The main effect of fractional crystallisation is that over time, as the magma cools, it changes from an iron- and magnesium-rich basic magma, to an iron- and magnesium-poor intermediate magma, and ultimately a silicon-rich acidic magma.

Each of these types of magma has certain characteristic minerals which crystallise from it: olivine and pyroxene from basic magmas, amphiboles from intermediate magmas, and quartz from acidic magmas.



Intrusive rocks:	Gabbro	Diorite	Granite
Effusive rocks:	Basalt	Andesite	Rhyolite
Explosive rocks:		Ignimbrite	



Very generally, basic rocks tend to be dark in colour, and acidic rocks tend to be light in colour, with intermediate rocks somewhere in between.

This doesn't mean there are no dark minerals in acidic rocks – some mica is very dark – but there are much more dark minerals in the basic rocks, and much more lighter minerals in acidic rocks. The colour of the rock is therefore an important first guide to identifying it.

Olivine: Yellow-green, generally anhedral (no regular shape)

Pyroxene: Black, generally long thin needle crystals where euhedral

Amphibole: Black, generally stubby rectangular crystals where euhedral

Mica: Can be either golden or dark, stacked flat sheets

Plagioclase feldspar: White, generally rectangular crystals where euhedral

Alkali feldspar: White or pink, generally anhedral

Quartz: Clear glassy, generally anhedral

Texture

Minerals crystallise as the magma cools. If the magma takes a long time to cool, the crystals can take a long time to grow, and will be large or coarse in size. If the magma cools very quickly, the crystals might be very fine – too small to see without a powerful microscope. So the texture of a rock can tell us something very important about how it formed.

Intrusive igneous rocks which form large batholiths underground can take a very long time to cool – due to the small difference in temperature between the magma and the surrounding rocks. Minerals crystallising to form these rocks can take a long time to grow, and so these rocks are generally formed of coarse crystals. This is referred to as a phaneritic texture.

Extrusive rocks, which are erupted from a volcano, cool very, very quickly – chilled by the surrounding cold land and air. Minerals crystallising in these rocks are generally too small to see. This is referred to as an aphanitic texture.

Sometimes, magma will sit in a magma chamber for some time before a volcanic eruption happens. In cases like this, some crystals can grow quite large in the magma chamber, but the rest of the rock crystallises very quickly once the eruption happens. Rocks formed like this have some large crystals surrounded by a groundmass of very fine crystals too small to see. This is referred to as a porphyritic texture.

Extrusive volcanic rocks can have bubbles – which tells us there was gas in the lava. You might notice these as holes in a rock – which are often later filled in by new crystals, usually a type called zeolites. This is a vesicular texture.

Extrusive volcanic rocks formed from explosive eruptions often don't look crystalline at all. These will have a fragmented texture, with grains of different sizes and shapes.

Combining composition and texture to determine style of formation

Igneous rocks are named based on their style of formation (which is reflected by the texture) and their composition. The table below gives the names of the main kinds of intrusive and extrusive igneous rocks.

	Basic	**Intermediate**	**Acidic**
Intrusive **Phaneritic texture**	Gabbro	Diorite	Granite
Volcanic – Lava **Aphanitic texture *or* Porphyritic texture**	Basalt	Andesite	Rhyolite
Volcanic – Explosive **Fragmented texture**		Ash	

Your task

You are provided with five kinds of igneous rocks: gabbro, basalt, granite, rhyolite, and a volcanic ash.

	Location	Age	Rock Type
A	Carlingford, Co. Louth	Palaeogene	Gabbro
B1	Glenarm, Co. Antrim	Palaeogene	Basalt
B2	Linfield, Co. Limerick	Carboniferous	Basalt
C1	Carnsore Point, Co. Wexford	Silurian	Granite
C2	Dog's Bay, Co. Galway	Devonian	Granite
D1	Knockmahon, Co. Waterford	Ordovician	Rhyolite
D2	Parys, Anglesey, Wales	Ordovician	Rhyolite
E	Vesuvius, Napoli, Italy	Holocene	Volcanic ash

You are also provided with two beach sand sediments:

	Location	Age	Sediment Type
1	Stromboli, Italy	Holocene	Beach sand
2	Owey Island, Co. Donegal	Holocene	Beach sand

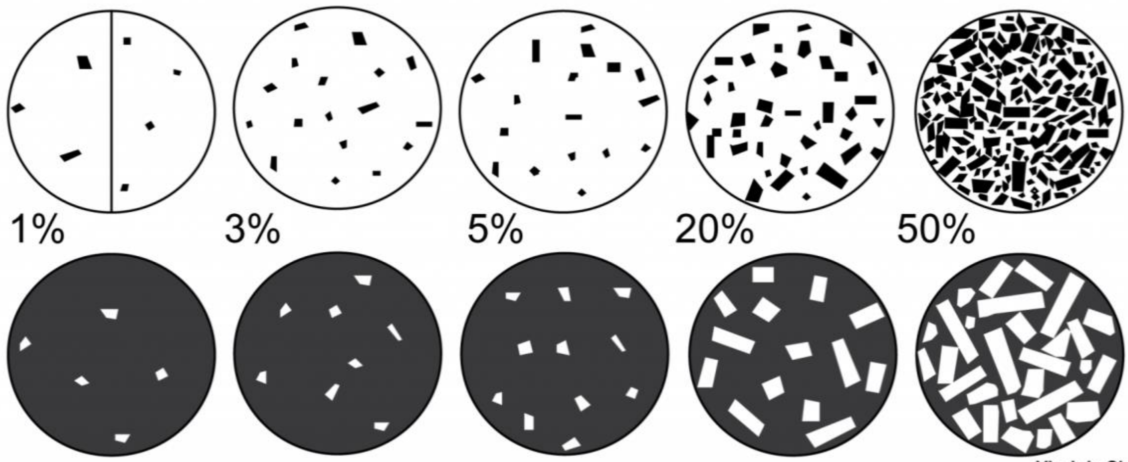
Your task is to examine and describe one of each kind of igneous rock, and both of the sediments. Fill in the table below (or in the provided spreadsheet) to give a description of each kind of rock and sediment, and answer the questions after the table.

For each rock, you need to describe:

Colour: This is the colour of a fresh, unweathered surface. Give a single average colour – as if you were looking at it from a few metres away. Be specific – "Grey" is not informative. Most rocks are grey. "Medium dark grey" is informative. If there are both light and dark minerals, try to estimate the percentages.

Composition: The colour will be your main guide here. If you can identify any minerals, this will help. Your options are:

- *basic*, mostly dark with some light minerals; or
- *acidic*, mostly light with some dark minerals.



Estimating Percentage of Light vs Dark Minerals

Texture: Your options are:

- *aphanitic* (no visible crystals),
- *vesicular* (holes, sometimes filled with new crystal growth, floating in a fine or aphanitic groundmass),
- *porphyritic* (some large crystals, floating in a fine or aphanitic groundmass),
- *phaneritic* (visible crystals, generally similar sizes), or
- *fragmented* (not necessarily crystalline, broken up).

Crystal shape: Your options are

- *euhedral* (regular shape, with straight sides; this means the crystals were still growing in a liquid when the magma cooled to rock), or
- *anhedral* (no regular shape, crystals interlocking; this means magma solidified by the crystals growing until they used up the entire magma).

Style: Your options are

- *batholith intrusion* (cooled deep underground in a large body e.g. magma chamber);
- *dyke or sill intrusion* (cooled underground in a small intrusion);
- *effusive* (erupted onto the surface Hawai'ian or Strombolian style, with a volcanic lava flow); or
- *explosive* (erupted onto the surface Vulcanian or Plinian style, with a massive explosion).

Hazards: We also want to think about why it matters. In the lecture, I talked about the dangers of various volcanic eruptions – if you think a rock would have been associated with a dangerous eruption, note the hazards here.

For the sediments, we are going to cover materials like these in more detail later in the module, so we won't look at sediment-specific description for now. But, both sediments were eroded from igneous rocks, so you should try to fill out the table <u>to describe the original rocks which the sediments were eroded from</u>.

Colour: a single average colour, as for the rocks;

Composition: basic or acidic, similarly based on the colour;

Texture: obviously the sand grains are fragments, but are individual grains each made of visible crystals, or are the individual grains made of fragments of rock without visible crystals, etc;

Crystal shape: if you can see crystals in the grains, are any of them euhedral, or are they all anhedral?

Style: was the original rock formed by one of these types of intrusion, or eruption?

Hazards: Would the original rock have been associated with any hazards?

REMEMBER! This is not a test – this is a learning exercise. So, feel free to talk to each other, and try to figure things out together – but do make sure you are making the observations and descriptions yourself, even if you're working with others. You will get nothing from writing down an answer that someone else gives you, but seeing the difference between different rocks will help you learn. And if you're not sure – *ask*.

Rock	Colour	Composition	Texture	Crystal shape	Style	Hazards
A						
B						
C						
D						
E						
1						
2						

Questions

Q1.1 Which is darker, the gabbro A or the granite C?

Q1.2 Which is darker, the basalt B or the rhyolite D?

Q1.3 Is the difference between gabbro A and the basalt B similar to the difference between the granite C and the rhyolite D?

Q1.4 Which two rocks were formed from effusive eruptions?

Q1.5 Which two rocks have the smallest crystal size?

Q1.6 Which kind of rock do you think sediment 1 was eroded from?

Q1.7 Which kind of rock do you think sediment 2 was eroded from?

Laboratory 2: Metamorphic Rocks

In the Metamorphism lecture, we discuss how rocks change under high pressures and temperatures. These changes form different metamorphic rocks, depending on what temperature and pressure the rocks were under. That's what this lab aims to explore.

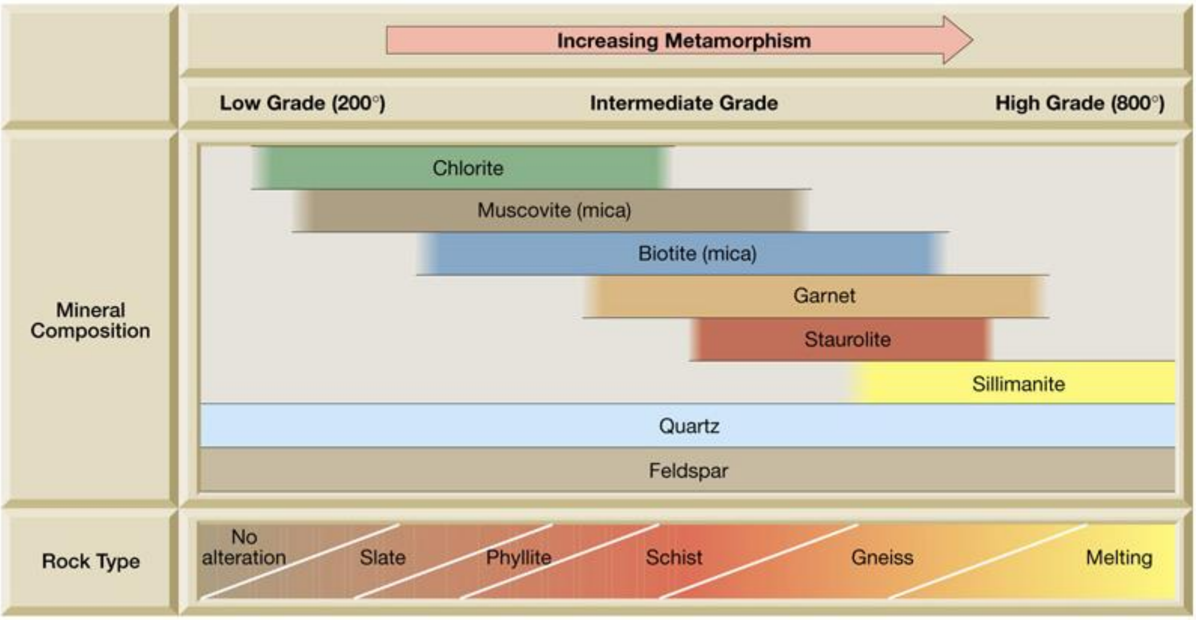
Similarly to the igneous rocks of the first lab, when looking at metamorphic rocks, there are two properties which are particularly important. These are the composition or chemistry of the rock; and the texture of the rock. Both of these properties can tell us very important details, about what the rocks originally were, and what conditions they've been subjected to.

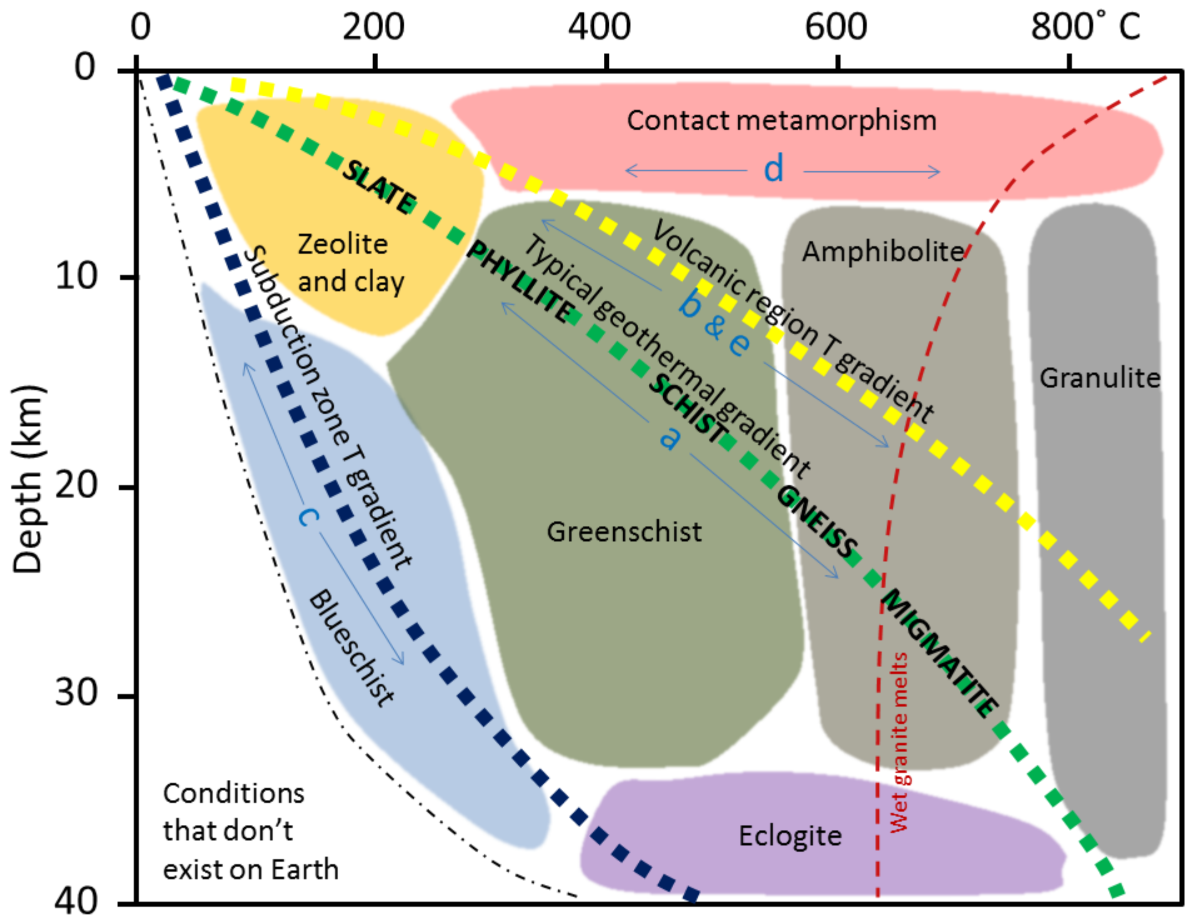
Composition

Two factors control the composition of metamorphic rocks. One is the composition of the original rock; and the other is the composition of the metamorphosed version.

Rocks with distinctive compositions before metamorphism are relatively straightforward. Limestones which are metamorphosed become marbles – easily identified by their high calcite (calcium carbonate) content. Quartz-rich sandstones are metamorphosed to quartzite – easily identified by their high quartz content. Examining the composition of these rocks tells us what the original rock was.

However, for most metamorphic rocks, it is difficult to identify the original rock without a geological microscope – if not a precise chemical analysis. In these cases, examining their composition in hand specimen can't tell us what the original rock was – but it can tell us something about the conditions of metamorphism. As pressure and temperature increases on a rock, different new minerals will grow.





Blueschists contain the mineral glaucophane. Amphibolites contain amphibole minerals. Granulites commonly contain pyroxene minerals. Eclogites contain the mineral garnet, and a green pyroxene mineral called omphacite.

Chlorite: Pale green, stacked thin flat sheets

Muscovite mica: Golden stacked thin flat sheets

Biotite mica: Black stacked thin flat sheets

Garnet: Generally dark red dodecahedron (D12)

Staurolite: Reddish brown, generally long and thin, often occurs twinned in a cross

Silliminite: Yellowish, fibrous or needlelike

Amphibole: Black, generally stubby rectangular crystals

Glaucophane: a type of amphibole which is blue

Pyroxene: Green or black, generally long thin needle crystals where euhedral

Calcite: Clear glassy to white, rhombohedral where euhedral, reacts with acid

Plagioclase feldspar: White, generally rectangular crystals

Alkali feldspar: White or pink, generally anhedral

Quartz : Clear glassy, generally anhedral

Pyrite: Iron sulphide. Cubic, pale golden.

Chalcopyrite: Copper iron sulphide. Cubic, brassy, darker than pyrite.

Galena: Lead sulphide. Cubic or octahedral, grey metallic.

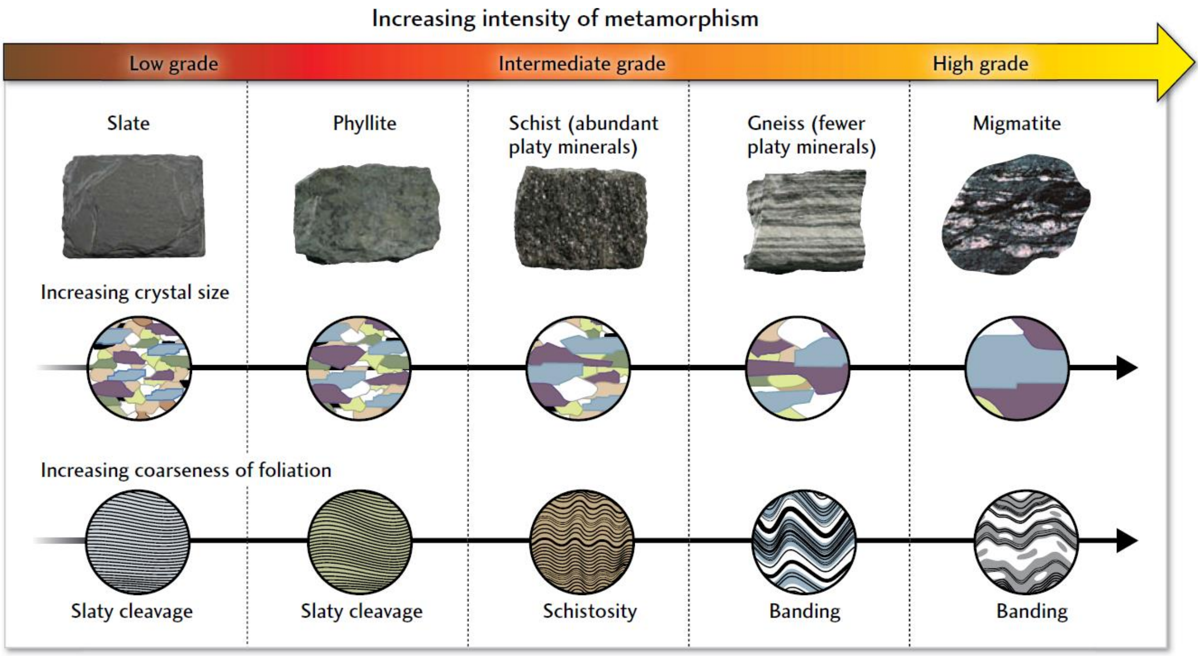
Sphalerite: Zinc-iron sulphide. Cubic, grey resinous.

Pyrrhotite: Iron sulphide. Hexagonal pale golden.

Texture

There are two aspects to the texture of metamorphic rocks – crystal size, and layering.

The general rule is that as pressure and temperature increases, new crystals grow larger, and layering becomes more clearly defined and thicker.



Source: Fig. 6.6, Grotzinger, J.P. and Jordan, T.H. 2014 Understanding Earth (7th ed.). New York: WH Freeman.

The layering you see in metamorphic rocks is *not* original layering from the rock pre-metamorphism – it is new layering caused by the metamorphism. In some rocks the layering will be flat – in others, you may notice that the layers have been deformed and folded by the intense pressure. Imagine how much pressure it takes to deform rocks.

Your task

You are provided with five kinds of rocks: slate, schist, gneiss, quartzite, and a hydrothermally altered mudstone.

	Location	Age	Rock Type
F	Llanberis, Wales	Ordovician	Slate
G1	Connemara, Co. Galway	Cryogenian	Schist
G2	Malin Head, Co. Donegal	Cryogenian	Schist
H1	Kimore Quay, Co. Wexford	Mesoproterozoic	Gneiss
H2	Inishtrahull, Co. Donegal	Palaeoproterozoic	Gneiss
I	Connemara, Co. Galway	Cryogenian	Quartzite
J	Parys, Anglesey, Wales	Ordovician	Hydrothermally altered mudstone

You are also provided with one beach sand sediment:

	Location	Age	Sediment Type
3	Kilmore Quay, Co. Wexford	Holocene	Beach sand

Your task is to examine and describe one of each kind of rock, and the sediment. Fill in the table below (or in the provided spreadsheet) to give a description of each kind of rock and sediment, and answer the questions after the table.

For each rock, you need to describe:

Colour: This is the colour of a fresh, unweathered surface. Give a single average colour – as if you were looking at it from a few metres away. Be specific – "Grey" is not informative. Most rocks are grey. "Medium dark grey" is informative. If there are both light and dark minerals, try to estimate the percentages.

Texture: Your options are:

- *fractured* – where the rock has been broken up by alteration
- *unlayered* – uniform, with no visible layers
- *slaty* – layering not necessarily visible, but the rock splits along very flat surfaces
- *schistose* – thin visible layers, defined by flat minerals such as muscovite mica
- *banded* – thick visible alternating light and dark layers

Crystal size: your options are:

- *aphanitic* – no visible crystals
- *fine* – crystals visible but smaller than 1mm
- *coarse* – crystals larger than 1mm

Permeability: Your options are:

- High permeability – water could flow through the rock
- Low permeability – water could barely or not at all flow through the rock

Facies: Your options are Contact, Zeolite, Blueschist, Greenschist, Amphibolite, Granulite, and Eclogite. See the diagram at the top of page 12.

Setting: Your options for the metamorphic setting are:

- *Contact metamorphism* – Contact facies;
- *Regional metamorphism* – Zeolite/Greenschist/Amphibolite/Granulite facies; or
- *Subduction zone metamorphism* – Blueschist/Eclogite facies.

Potential use: Some rocks are quarried and broken up to be used as aggregate for construction – for example, underneath the tarmac surface of roads. Some rocks can be used in roofing. Some can be sources of minerals. Based on your observations, can you suggest if each of the rocks has any potential use?

For the sediment, you can skip texture, permeability, and use; but note it's colour and the size of the crystals, and try and figure out which kind of metamorphic rock it was eroded from, including the facies and setting.

Rock	Colour	Texture	Crystal size	Permeability	Facies	Setting	Use?
F							
G							
H							
I							
J							
3							

Questions

Q2.1 List rocks slate F, schist G, and gneiss H, in order of crystal size, from smallest to largest?

Q2.2 List rocks slate F, schist G, and gneiss H, in order of layer thickness, from thinnest layers to thickest layers?

Q2.3 List rocks slate F, schist G, and gneiss H, in order of metamorphic grade, from lowest metamorphic grade to highest metamorphic grade?

Q2.4 Which of these rocks has the highest permeability?

Q2.5 How does the permeability compare between rocks slate F, schist G, gneiss H, and quartzite I?

Q2.6 Which of rocks slate F, schist G, gneiss H, and quartzite I could most easily be split into thin flat sheets?

Q2.7 Which kind of rock do you think sediment 3 was eroded from?

GEOGRAPHY READING WEEK: Virtual Field Trip to Parys, Wales

There are too many students on this module to bring you all on an overseas field trip – so we'll do the next best thing. This week's virtual field trip to Parys, on the island of Anglesey in Wales, consists of a series of videos I recorded on site, along with some additional photos, all geolocated on an ArcGIS Story Map. You can go through the tour stop by stop, see the rocks around the area, and how it impacted society in the local region and beyond.

It should take around one hour to complete.

There's also an independent exercise starting on the next page.

Reading Week Exercise: Stratigraphy and Geological Time

To fully appreciate the depth of geological history, and to better understand how the Geologic Time Scale was put together, it is important to have an understanding of geological time, particularly the concepts of relative dating and absolute dating. In earth science, this is referred to as stratigraphy. This is what this exercise aims to explore.

Task 1 – Relative Dating:

Even when we don't know any numbers for the age in years of particular events, we can still determine in what sequence or order those events occurred. This is called relative dating; we might not know exactly how old one layer or event is, but we can determine whether it is older or younger relative to other layers and events.

There are a few principles of stratigraphy which can be used in relative dating, to determine a sequence of events.

I. The Principle of Original Horizontality
Layers of sediments (or sedimentary rocks) were originally deposited as horizonal layers. If such layers are now not horizontal, then some force must have acted on them after they were deposited.

II. The Principle of Superposition
In any undisturbed sedimentary sequence, the layer at the bottom is older than any layer above it.

III. The Principle of Cross-Cutting Relationships
If a layer or feature "X" cuts or in any way effects or modifies layer or feature "Y", then "Y" must be older, as it must have existed first to be cut, effected, or modified.

IV. The Principle of Included Fragments
If a layer "X" contains fragments of layer "Y", layer "Y" must be older than layer "X".

V. The Principle of Faunal Succession
As life evolved through time, fossils succeed each other in a specific and predictable order. This order can be used to determine the relative ages of layers with fossils: layers with similar fossils are related in age, and layers with succeeding fossils are younger.

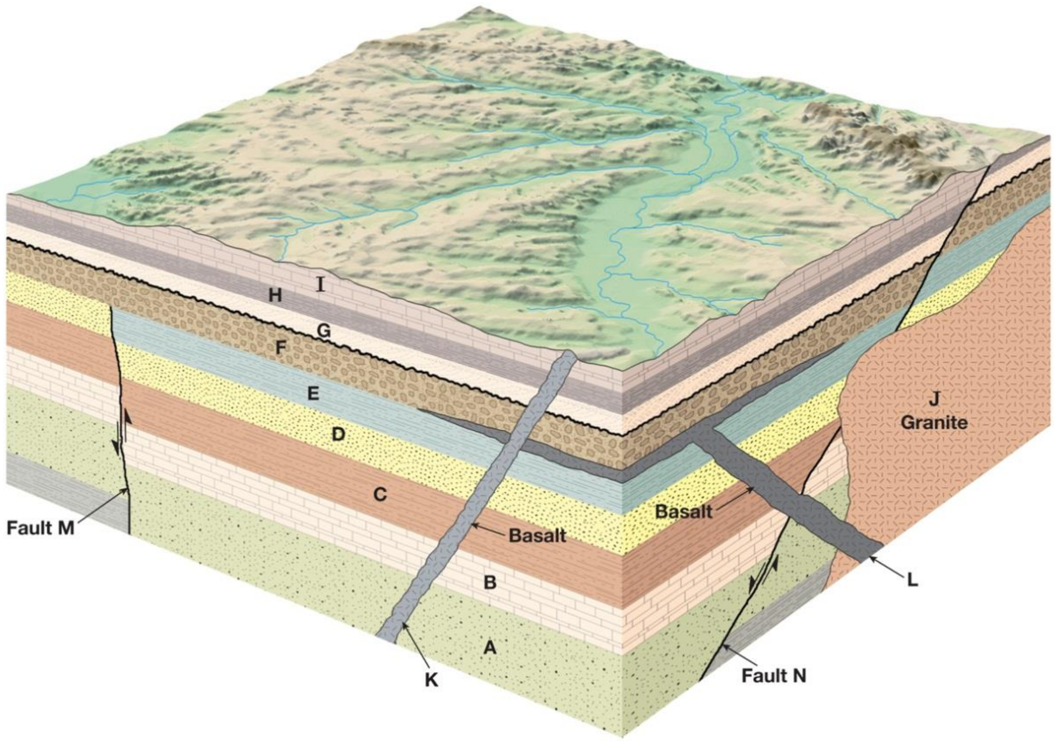


Figure 1: Geological block diagram of a hypothetical region.

R.1 Using the Principles of stratigraphy listed above, determine the sequence of geological events which have occurred in Figure 1. M and N are faults, J, K & L are igneous intrusions, and all other layers are sedimentary rocks.

Oldest Youngest

R.2 Which principle of stratigraphy did you apply to determine the relative ages of H and I?

R.3 Which principle of stratigraphy did you apply to determine the relative ages of M and F?

R.4 Explain the relationship between fault N and igneous intrusion J.

Task 2 – Radiometric Dating

The principles of stratigraphy you used above are the same principles which were used to determine the geologic time scale – the main geologic Systems or Periods, and their subdivision into Series and Stages. Determining how numbers for how old, how many years ago each Period or event was, came much later.

The discovery of radioactivity and its subsequent understanding has provided a reliable means for calculating the numerical age in years of many Earth materials. Key to this is the concept of isotopes. Some atoms have several different varieties called isotopes, with slightly different numbers of particles in their atomic nucleus. Carbon, for example, comes with 12, 13, or 14 (written as ^{12}C, ^{13}C, and ^{14}C). Uranium comes in a variety of sizes, from ^{232}U to ^{238}U. Some isotopes are stable. Some aren't – we call these radioactive.

Radioactive atoms, such as the isotope uranium ^{238}U, emit particles from their nuclei that we detect as radiation. Ultimately, this process of decay produces an atom that is stable and no longer radioactive. For example, eventually the stable atom lead ^{206}Pb is produced from the radioactive decay of ^{238}U.

The radioactive isotope used to determine a radiometric date is referred to as the parent isotope. The amount of time it takes for half of the radioactive nuclei in a sample to change to their stable end product is referred to as the half-life of the isotope. The isotopes resulting from the decay of the parent are termed the daughter products. For example, if we begin with one gram of radioactive material, half a gram would decay and become a daughter product after one half-life. After the second half-life, half of the remaining radioactive isotope, 0.25 or ¼ of the original amount (½ of ½), would still exist. With each successive half-life, the remaining parent isotope would be reduced by half (Figure 3).

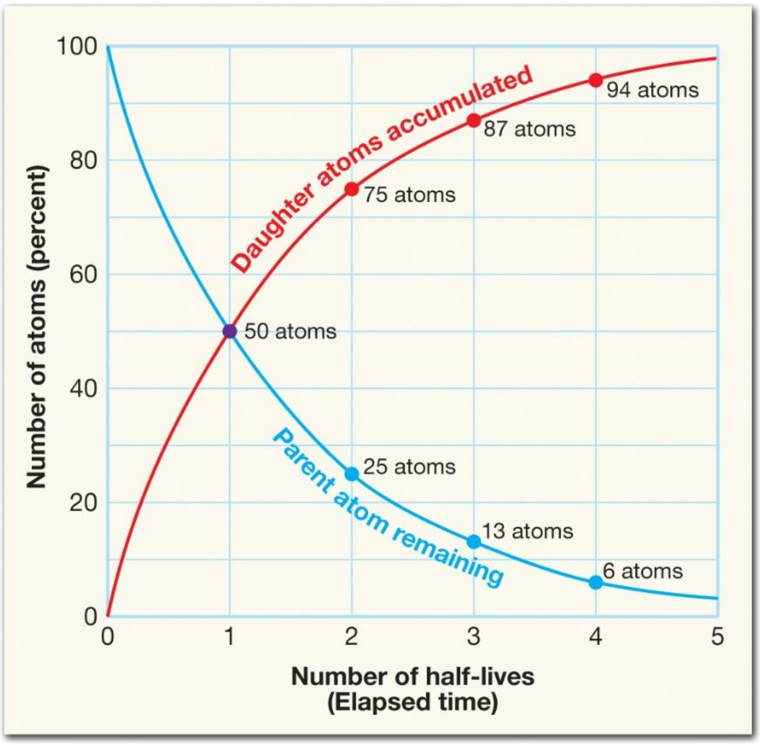


Figure 2: Radioactive decay curve

R.5 For the recent past, carbon dating may be used – based on the decay of carbon-14 (^{14}C). Knowing that the half life of ^{14}C is 5730 years complete Table 1 by calculating the 'percent of ^{14}C remaining' by years before present (B.P.).

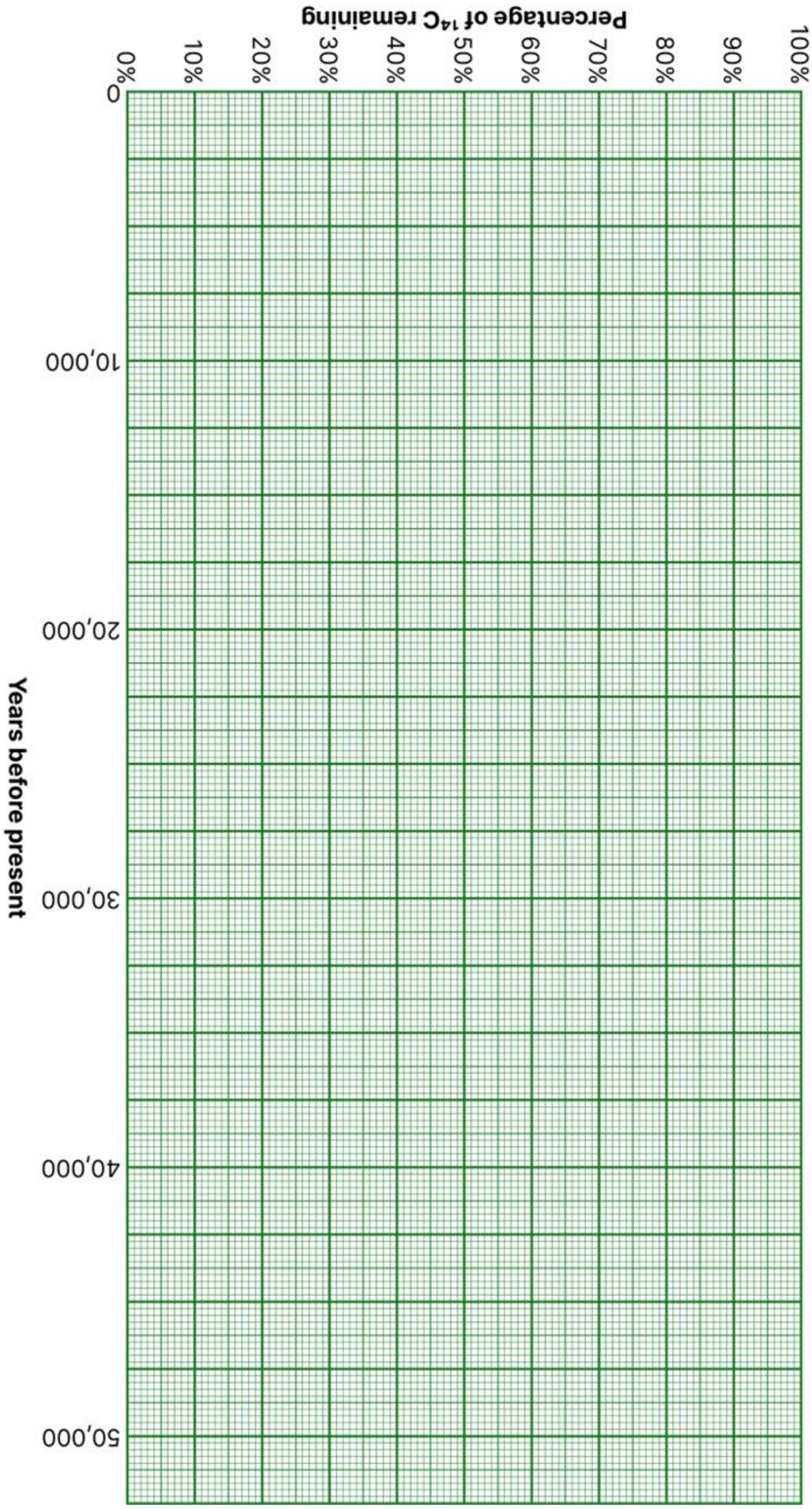
Years B.P.	0	5,730	11,460	17,190	22,920	28,650	34,380	40,110	45,840	51,570
% of ^{14}C remaining										

Table 1

Using the graph paper on the next page, construct a line graph from the data in Table 1. The result should be a smooth, curving line through all points. Use this graph of ^{14}C decay to answer the following questions:

R.6 In 1991, hikers in the Alps discovered an almost perfectly preserved body of a prehistoric man. Carbon dating of samples from the site established the death of the man to be approximately 5,300 years ago. What percentage of the original carbon-14 remained in the body?

R.7 A 1998 study provided evidence that the tropics were much colder during the last glacial maximum than previously thought. Investigators retrieved two ice cores from the bottom of the ice cap at the summit of an extinct Bolivian volcano named Sajama. Trapped within the cores were insects and bark fragments from local trees. Carbon from organic material near the bottom of the cores dated to the coldest period of the last ice age. If those samples had 5.5 percent of their original carbon-14, approximately how many years ago did the glacier atop Sajama begin to form?


Percentage of ^{14}C remaining
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Years before present
0
10,000
20,000
30,000
40,000
50,000

Laboratory 3: Clastic Sedimentary Rocks

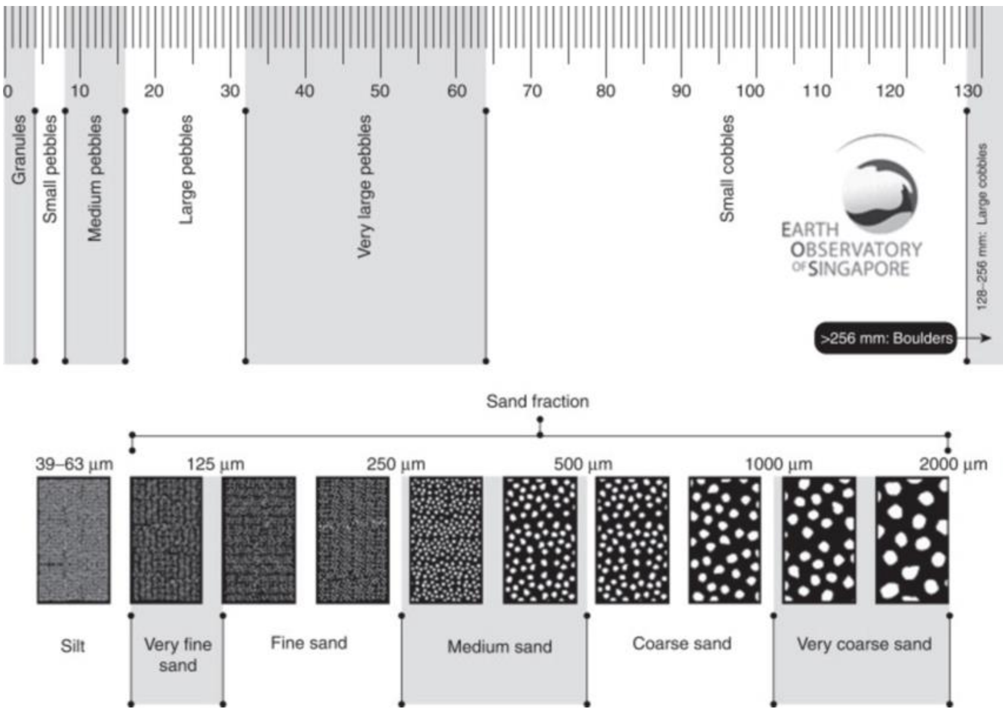
In the Erosion, Transport, and Deposition lecture, we discuss how sediments are transported by gravity, air, water, and ice. We cover how sediments change during transport, and how characteristically different sediments are deposited in different environments. That's what this lab aims to explore.

For the igneous and metamorphic rocks we looked at in the previous labs, the composition and texture were the key features. In clastic sedimentary rocks, texture is still a key factor; but grain size is more important than composition, because sediments can be eroded and transported from many different kinds of rocks.

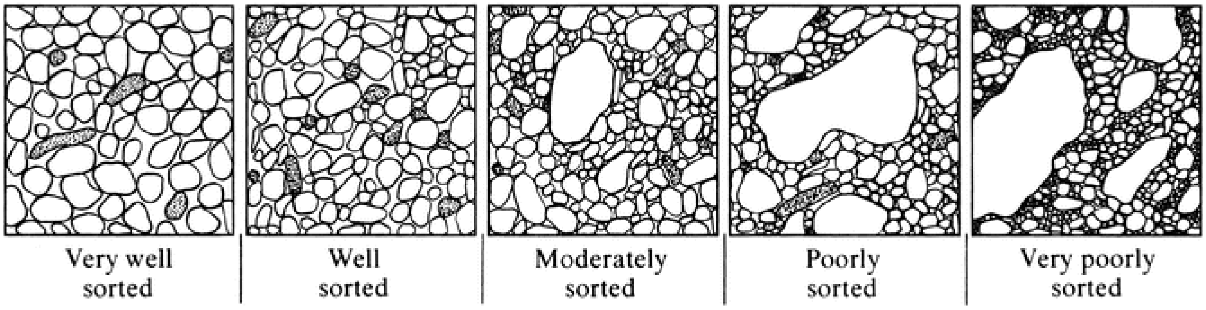
Characteristics

There are a few key characteristics used in describing sediments and sedimentary rocks.

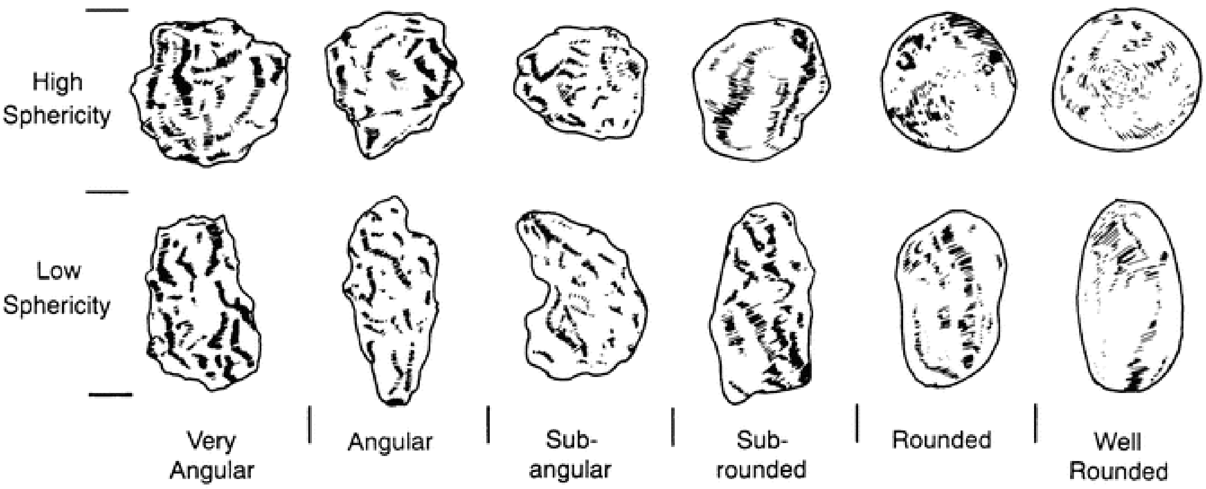
Grain size: The size of sedimentary grains can range from mud (smaller than 0.0039mm, which is 1/256th of a mm) to boulders (larger than 256 mm). The size of the grains can help distinguish the agent of transport: air cannot transport grains larger than fine grained sand over significant distances, water requires extremely strong currents to transport grains larger than pebbles, while glaciers and gravity can transport even the largest blocks. Use the chart below (to scale) as a guide – and remember, it's the maximum grain size which is of interest, because that's what tells us about the strength of the transport process.



Sorting: A well-sorted sediment is one where all the grains are approximately the same size. A poorly sorted sediment will have a wide range of grain sizes. This is key to interpreting how a sediment was deposited, as flow processes such as wind or water currents tend to sort sediment quite rapidly. As a flow slows down, the largest grains it carries are deposited, leaving a well-sorted deposit of that grain size. More rapid deposition, in which a flow slows significantly or stops entirely, will deposit all the sediment carried by that flow, leaving a poorly sorted sediment. This is essentially what happens with gravity and glacial deposition, which generally have very poorly sorted sediments.

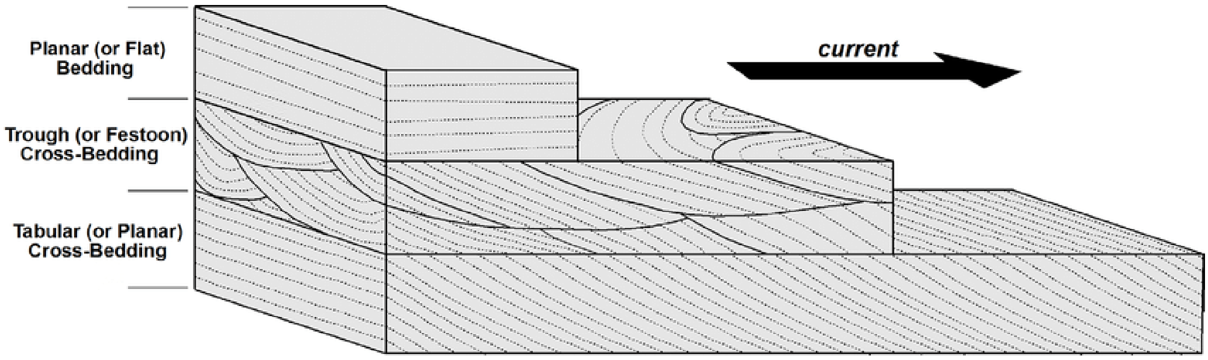


Rounding and Sphericity: Sediment which has just broken off a rock is usually quite angular, with sharp corners and edges, with a variety of shapes – elongated, blocky, or platy. As sediment is transported within a flow, grains will collide with each other and bounce off surfaces (e.g. a riverbed). These impacts tend to smooth off sharp corners and edges, becoming more rounded, and more spherical. The higher the energy of the flow, and the longer the distance of transport, the more the grains become more rounded and spherical. So, in general, angular sediment with low sphericity has been transported only a short distance – while rounded, highly spherical sediment must have had a long distance of transport. The main exception is in glaciers, where there is no grain-to-grain contact, as the sediment is separated by solid ice. Glacial sediments typically do not become more rounded or spherical with longer transport distances.

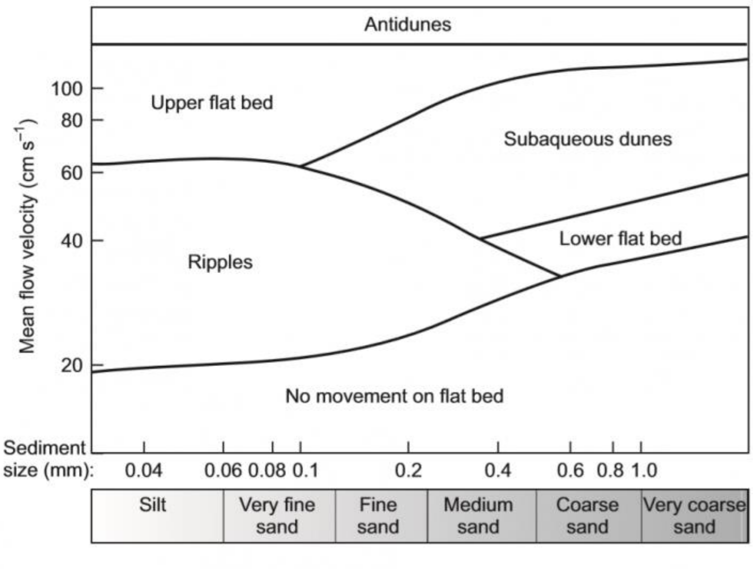


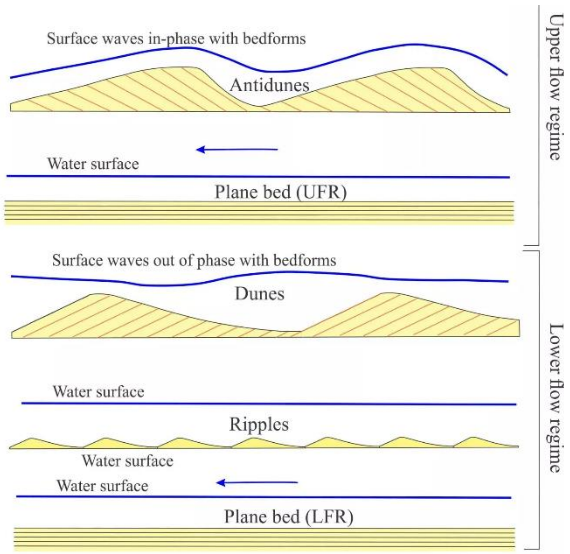
Porosity/Matrix/Cement: These three characters are different answers to the same question: what is in between the grains? If the space in between the grains is, well, space, this is called porosity. If the space between grains is filled with smaller grains (usually silt or mud), this is called a matrix. If crystals have grown in the space between grains, this is called a cement. The presence of a matrix usually goes with poor sorting, and tells us something about the deposition. If there's a high porosity or cement, that tells us that the rock did not undergo significant compaction, with the cement indicating fluids moving through the rock to form crystals, well after deposition.

Sedimentary structures: During deposition, sediments can form sedimentary structures such as planar (flat) bedding or cross-bedding (ripples).



These are extremely useful, as they can tell us about the depositional flow velocity.





Graded bedding (a gradual decrease in grain size) can tell us if a flow was slowing down while depositing sediments.

Colour: Some colours are distinctive. Red is usually from rusting of iron, indicating a setting open to oxygen, like deserts and rivers. Black usually indicates a high organic content, with very little oxygen for decay, like quiet deep marine environments.

Oil and Gas systems: Oil and gas are produced when a *source rock* with a high content of organic matter is heated enough to produce liquid, which then *migrates* to a *reservoir*, where it is trapped by a *seal*.

Your options for this answer are either <u>source</u>, <u>reservoir</u>, or <u>N/A</u> (not applicable). Source rocks are typically fine grained, and are typically black due to the high organic matter content. Reservoir rocks require a high porosity and permeability: space between the grains for the oil or gas to fill, and enough connections for the oil and gas to be able to flow into it.

Your task

You are provided with five kinds of clastic sedimentary rocks: aeolian desert dune sandstone, river sandstone, glacial diamictite, shallow marine sandstone, and deep marine black shale.

	Location	Age	Rock Type
K	Merseyside, England	Permian	Aeolian sandstone
L	Lumsdin's Bay, Co. Wexford	Devonian	River sandstone
M1	Port Askaig, Islay, Scotland	Cryogenian	Glacial diamictite
M2	St. Mary's, Newfoundland, Canada	Ediacaran	Glacial diamictite
N	Rosroe, Co. Galway	Ordovician	Marine sandstone
O	Booley Bay, Co. Wexford	Cambrian	Black shale

We'll soon begin talking about the geological history of Ireland. Not all of these rocks are from Ireland – there's rocks from Galway and Wexford, but also England, Scotland, and Newfoundland. Yet they are all relevant to the geology of Ireland. At the time they formed, the rocks from Newfoundland were closer to Wexford than Galway was. Mind blown?

You are also provided with three sediments:

	Location	Age	Sediment Type
4	Ballyheigue, Co. Kerry	Holocene	Dune sand
5	Mulkear, Co. Limerick	Holocene	River sand
6	Connemara, Co. Galway	Quaternary	Glacial till

Your task is to examine and describe one of each kind of rock, and the sediments. Fill in the table below (or in the provided spreadsheet) to give a description of each kind of rock and sediment, and answer the questions after the table.

Rock	Colour	Grain size	Sorting	Roundness/ sphericity	Porosity/ Matrix/Cement	Sedimentary structures	Oil & Gas systems
K							
L							
M							
N							
O							
4							
5							
6							

Questions

Q3.1 How does the aeolian dune sandstone rock K compare to the aeolian dune sand sediment 4?

Q3.2 How does the river sandstone rock L compare to the river sand sediment 5?

Q3.3 How does the glacial diamictite rock M compare to the glacial till sediment 6?

Q3.4 Is the difference between the aeolian dune sandstone rock K and the river sandstone rock L similar to the difference between the aeolian dune sand sediment 4 and the river sand sediment 5?

Q3.5 Which rock is the most poorly sorted?

Q3.6 Which rock is the most well sorted?

Q3.7 Which rock has the most rounded grains?

Q3.8 Which rock has the highest porosity?

Laboratory 4: Carbonate Sedimentary Rocks

In the Carbonates lecture, we discuss how carbonate sediments are different to clastic sediments. Erosion and transport are less important – and biology is much more important, with most carbonate made as parts of shells and skeletons. Still, there can be huge variations in carbonate rocks produced in different environments. That's what this lab aims to explore.

Carbonate components

Instead of thinking about grain size, shape, and sorting – as we did in the previous lab on clastic sediments – the more important characteristic in carbonates is what components the rock is made of.

Allochems: These are carbonate grains. There are four main types:

> Bioclasts: These are fragments of carbonate produced by organisms – fossils, basically. There's a little more detail on these below.
>
> Intraclasts: Fragments of semi-lithified carbonate, re-sedimented – usually carbonate mud (micrite), identifiable by their irregular shape.
>
> Peloids: Faecal pellets of carbonate mud (micrite), identifiable by their regular rounded sub-spheroidal shape.
>
> Ooids: Spherical grains formed like a snowball, by rolling around in carbonate mud, building up layers around the core. Identifiable by their spherical shape.

Micrite: Mud, but made up of carbonate.

Sparite: Carbonate cement – usually large crystals.

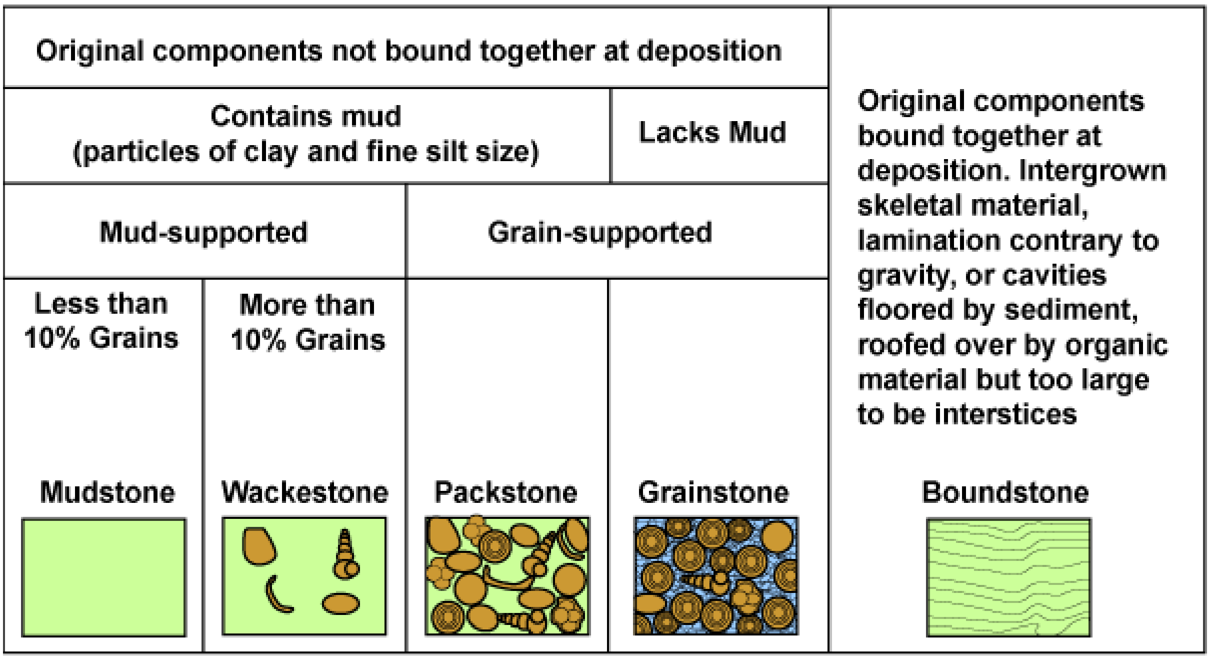
Clastics: Grains of quartz and other components which might have been transported into the area by processes discussed in Lab 3. Usually a minor component.

Porosity: Gaps or holes in the rock, which can be primary (always holes since the rock formed), or secondary (formed more recently by parts dissolving).

Alteration: Carbonate can be altered very easily, by fluids moving through the rock. Most commonly, this is the minerals calcite and aragonite recrystallising, but alteration to dolomite is also relatively common. Dolomite is often slightly yellowish to brownish.

Carbonate classification

It can be difficult to identify all of these components without using a microscope, so when we're just looking at hand samples of carbonate rocks, or sequences of carbonate rocks in the field, we generally use a classification scale called the Dunham classification. This looks at micrite mud and grains, and the amount and relationship between them to classify carbonates into one of 5 categories.

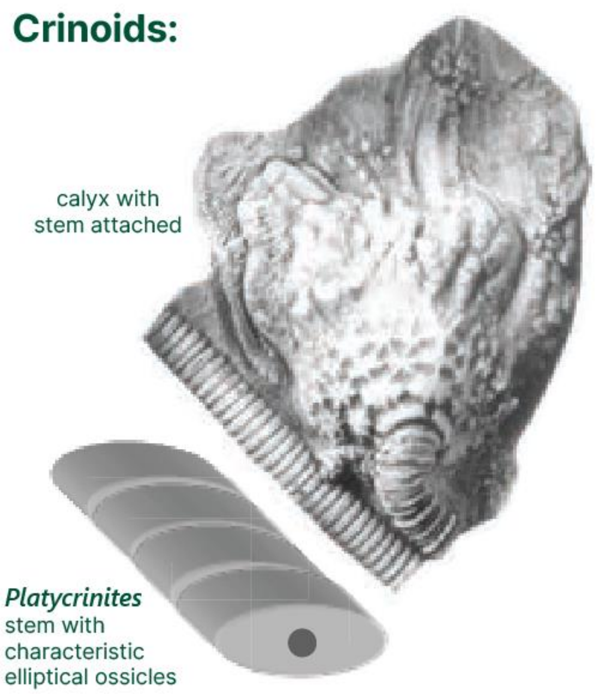


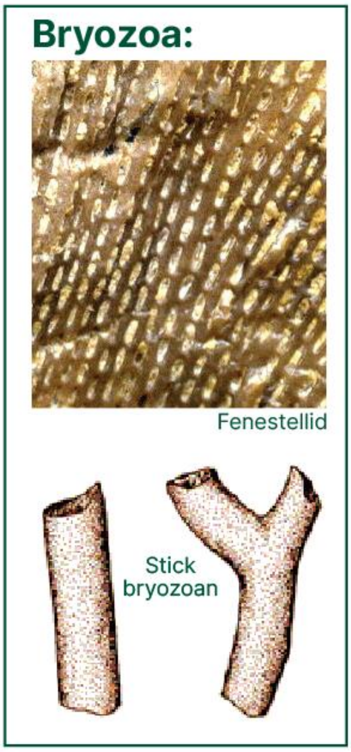
C. G. St. C. Kendall, 2005 (after Dunham, 1962, AAPG Memoir 1)

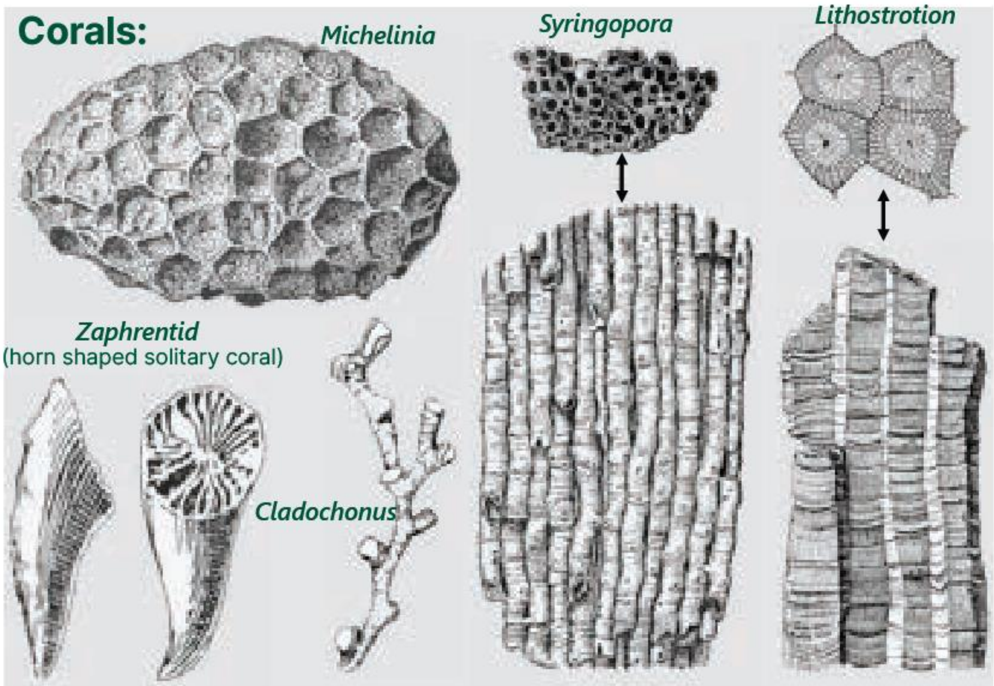
Fossils

Fossils can help interpret the environments, as different organisms like to live in different conditions – so if we know the conditions in which a fossil organism liked to live, finding it in a rock tells us it was living in or sourced from those conditions. We haven't covered fossils so you won't know all this, but you should be able to identify some of the fossils in these rocks from the examples on the following pages.

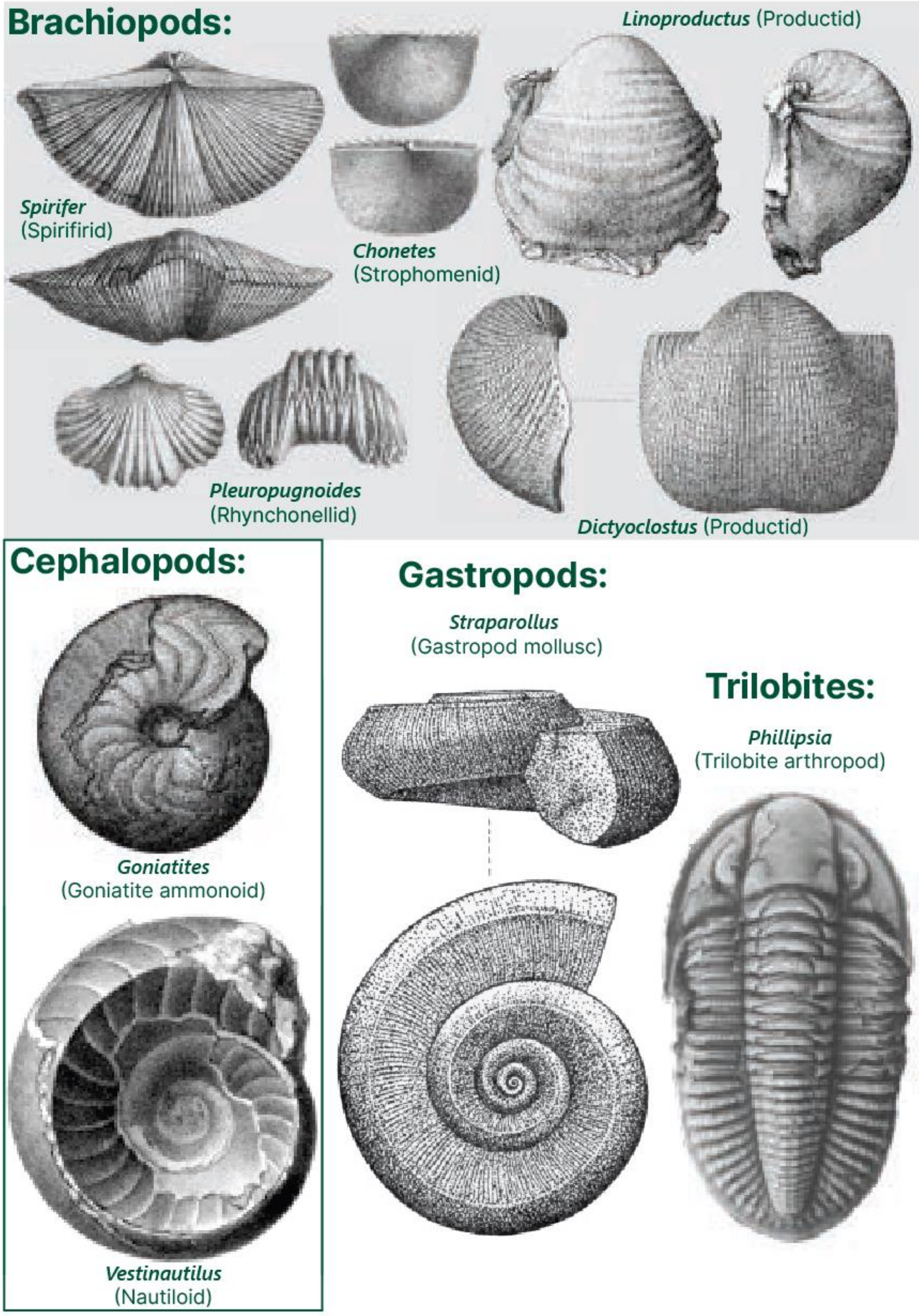
Some Carboniferous fossils







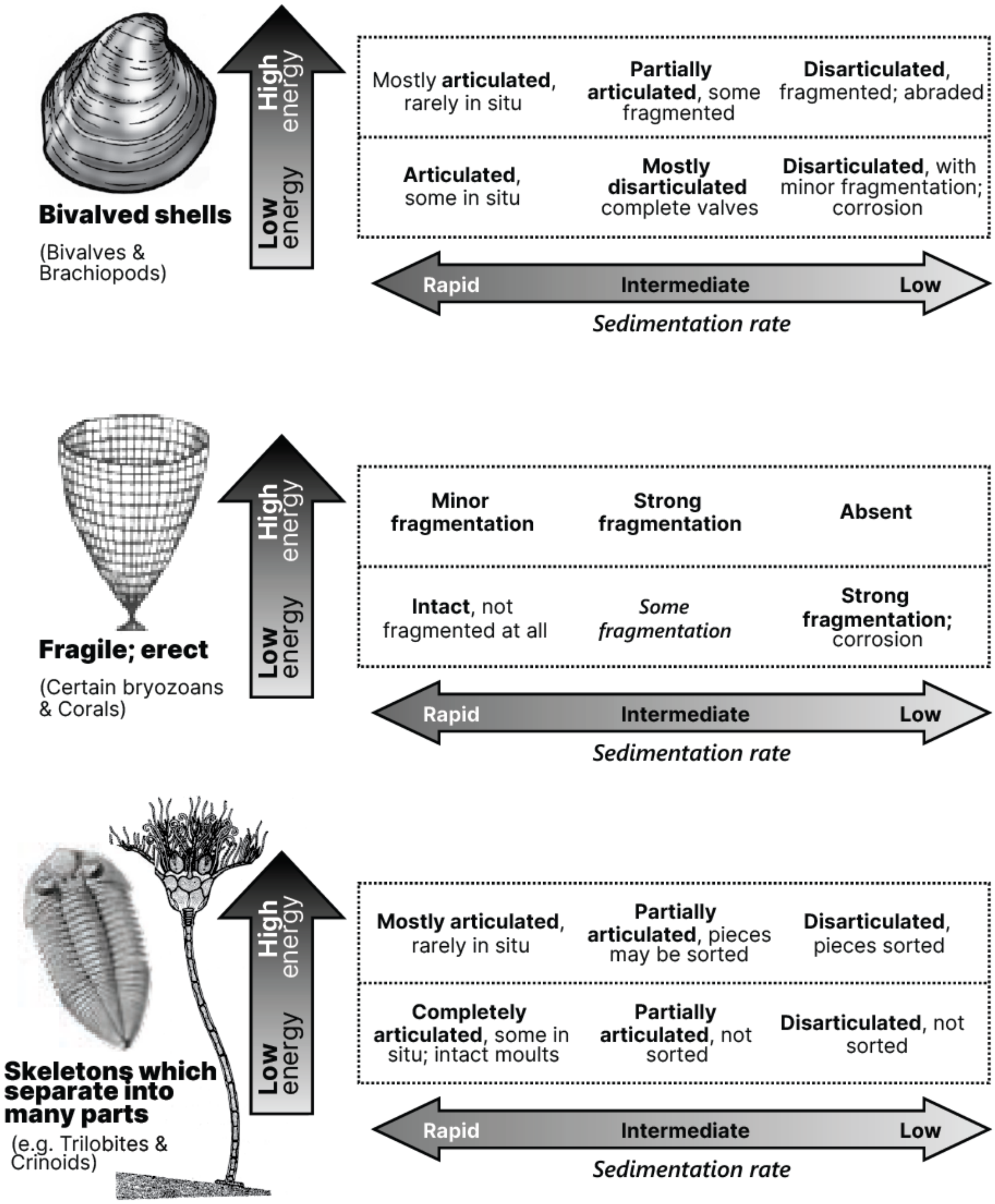
Some Carboniferous fossils



We can also learn about environments from how well the fossils are preserved.

Taphonomy is the study of processes which may have acted on the remains of a creature after death, thus influencing the type of fossil preservation. Understanding taphonomic processes is important in trying to decipher the palaeoenvironmental conditions the organism in question lived in.

Taph-o-meters©:



Use the “taph-o-meters” above to try and interpret whether your samples formed in a low energy or high energy environment, and whether the sedimentation rate (how quickly the carbonate sediment built up on the seafloor) was low, intermediate, or rapid.

Your task

You are provided with four kinds of carbonate sedimentary rocks: shelf limestone, mud mound limestone, calciturbidite, and chalk.

	Location	Age	Rock Type
P	Lumsdin’s Bay, Co. Wexford	Carboniferous	Shelf
Q	Kildimo, Co. Limerick	Carboniferous	Mud mound
R	Foynes, Co. Limerick	Carboniferous	Calciturbidite
S	Glenarm, Co. Antrim	Cretaceous	Chalk

You are also provided with three sediments:

	Location	Age	Sediment Type
7	Sharp Island, Hong Kong	Holocene	Coral beach sand
8	Dog’s Bay, Co. Galway	Holocene	Foraminiferal beach sand
9	An Cheathrú Rua, Co. Galway	Holocene	Algal beach sand

Your task is to examine and describe one of each kind of rock, and the sediments. Fill in the table below (or in the provided spreadsheet) to give a description of each kind of rock and sediment, and answer the questions after the table.

For each rock note the components and allochems present, identifying fossils where possible, and give the energy and sedimentation rate using the fossil “taph-o-meters” or any other evidence. You should also identify the classification for each rock on the Dunham scale. To help make this easier, I’ve pre-filled some of the options, so you can simply circle or highlight the ones which apply.

For the sediments, the Dunham scale question doesn’t apply, but you can answer the other questions in the same way.

Rock	Colour	Components	Allochems	Fossils	Sedimentation rate & energy			Dunham Classification
P		Allochems	Bioclasts		RH	IH	LH	Mudstone
		Micrite	Intraclasts					Wackestone
		Sparite	Ooids		RL	IL	LL	Packstone
		Alteration	Peloids					Grainstone
Q		Allochems	Bioclasts		RH	IH	LH	Mudstone
		Micrite	Intraclasts					Wackestone
		Sparite	Ooids		RL	IL	LL	Packstone
		Alteration	Peloids					Grainstone
R		Allochems	Bioclasts		RH	IH	LH	Mudstone
		Micrite	Intraclasts					Wackestone
		Sparite	Ooids		RL	IL	LL	Packstone
		Alteration	Peloids					Grainstone
S		Allochems	Bioclasts		RH	IH	LH	Mudstone
		Micrite	Intraclasts					Wackestone
		Sparite	Ooids		RL	IL	LL	Packstone
		Alteration	Peloids					Grainstone
7		Allochems	Bioclasts		RH	IH	LH	
		Micrite	Intraclasts					
		Sparite	Ooids		RL	IL	LL	
		Alteration	Peloids					
8		Allochems	Bioclasts		RH	IH	LH	
		Micrite	Intraclasts					
		Sparite	Ooids		RL	IL	LL	
		Alteration	Peloids					
9		Allochems	Bioclasts		RH	IH	LH	
		Micrite	Intraclasts					
		Sparite	Ooids		RL	IL	LL	
		Alteration	Peloids					

Questions

Q4.1 Which of the four rocks shelf limestone P, mud mound limestone Q, calciturbidite R, and chalk S had the highest sedimentation rate?

Q4.2 Which of the four rocks shelf limestone P, mud mound limestone Q, calciturbidite R, and chalk S has intraclast allochems?

Q4.3 Which of the three rocks shelf limestone P, mud mound limestone Q, and calciturbidite R had the lowest energy environment?

Q4.4 Which of the three rocks shelf limestone P, mud mound limestone Q, and calciturbidite R contains the most complete fossils?

Q4.5 How does the permeability compare between the four rocks shelf limestone P, mud mound limestone Q, calciturbidite R, and chalk S?

Q4.6 To which of the rocks is sediment 7 most similar?

Q4.7 Do you think sediments 7, 8, and 9 were eroded from a limestone rock?

International Chronostratigraphic Chart

https://stratigraphy.org | **International Commission on Stratigraphy** | **v2024/12**

Eonothem	Erathem	System	Series	Stage	Numeric Age
					Present
Phanerozoic	Cenozoic	Quaternary	Holocene	Meghalayan	0.0042
				Northgrippian	0.0082
				Greenlandian	0.0117
			Pleistocene	Upper	0.129
				Chibanian	0.774
				Calabrian	1.80
				Gelasian	2.58
		Neogene	Pliocene	Piacenzian	3.600
				Zanclean	5.333
			Miocene	Messinian	7.246
				Tortonian	11.63
				Serravallian	13.82
				Langhian	15.98
				Burdigalian	20.45
				Aquitanian	23.04
		Paleogene	Oligocene	Chattian	27.30
				Rupelian	33.9
			Eocene	Priabonian	37.71
				Bartonian	41.03
				Lutetian	48.07
				Ypresian	56.00
			Paleocene	Thanetian	59.24
				Selandian	61.66
				Danian	66.00
	Mesozoic	Cretaceous	Upper	Maastrichtian	72.2 ± 0.2
				Campanian	83.6 ± 0.2
				Santonian	85.7 ± 0.2
				Coniacian	89.8 ± 0.3
				Turonian	93.9 ± 0.2
				Cenomanian	100.5 ± 0.1
			Lower	Albian	113.2 ± 0.3
				Aptian	121.4 ± 0.6
				Barremian	125.77
				Hauterivian	132.6 ± 0.6
				Valanginian	137.05 ± 0.2
				Berriasian	143.1 ± 0.6

Eonothem	Erathem	System	Series	Stage	Numeric Age
					143.1 ± 0.6
Phanerozoic	Mesozoic	Jurassic	Upper	Tithonian	149.2 ± 0.7
				Kimmeridgian	154.8 ± 0.8
				Oxfordian	161.5 ± 1.0
			Middle	Callovian	165.3 ± 1.1
				Bathonian	168.2 ± 1.2
				Bajocian	170.9 ± 0.8
				Aalenian	174.7 ± 0.8
			Lower	Toarcian	184.2 ± 0.3
				Pliensbachian	192.9 ± 0.3
				Sinemurian	199.5 ± 0.3
				Hettangian	~201.4 ± 0.2
		Triassic	Upper	Rhaetian	~205.7
				Norian	~227.3
				Carnian	~237
			Middle	Ladinian	241.464 ± 0.28
				Anisian	246.7
			Lower	Olenekian	249.9
				Induan	251.902 ± 0.024
	Paleozoic	Permian	Lopingian	Changhsingian	254.14 ± 0.07
				Wuchiapingian	259.51 ± 0.21
			Guadalupian	Capitanian	264.28 ± 0.16
				Wordian	266.9 ± 0.4
				Roadian	274.4 ± 0.4
			Cisuralian	Kungurian	283.3 ± 0.4
				Artinskian	290.1 ± 0.26
				Sakmarian	293.52 ± 0.17
				Asselian	298.9 ± 0.15
		Carboniferous – Pennsylvanian	Upper	Gzhelian	303.7 ± 0.1
				Kasimovian	307.0 ± 0.1
			Middle	Moscovian	315.2 ± 0.2
			Lower	Bashkirian	323.4 ± 0.4
		Carboniferous – Mississippian	Upper	Serpukhovian	330.3 ± 0.4
			Middle	Visean	346.7 ± 0.4
			Lower	Tournaisian	358.86 ± 0.19

Eonothem	Erathem	System	Series	Stage	Numeric Age
					358.86 ± 0.19
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	372.15 ± 0.46
				Frasnian	382.31 ± 1.36
			Middle	Givetian	387.95 ± 1.04
				Eifelian	393.47 ± 0.99
			Lower	Emsian	410.62 ± 1.95
				Pragian	413.02 ± 1.91
				Lochkovian	419.62 ± 1.36
		Silurian	Pridoli		422.7 ± 1.6
			Ludlow	Ludfordian	425.0 ± 1.5
				Gorstian	426.7 ± 1.5
			Wenlock	Homerian	430.6 ± 1.3
				Sheinwoodian	432.9 ± 1.2
			Llandovery	Telychian	438.6 ± 1.0
				Aeronian	440.5 ± 1.0
				Rhuddanian	443.1 ± 1.0
		Ordovician	Upper	Hirnantian	445.2 ± 0.9
				Katian	452.8 ± 0.7
				Sandbian	458.2 ± 0.7
			Middle	Darriwilian	469.4 ± 0.9
				Dapingian	471.3 ± 1.4
			Lower	Floian	477.1 ± 1.2
				Tremadocian	~486.85 ± 1.5
		Cambrian	Furongian	Stage 10	~491.0
				Jiangshanian	~494.2
				Paibian	~497.0
			Miaolingian	Guzhangian	~500.5
				Drumian	~504.5
				Wuliuan	~506.5
			Series 2	Stage 4	~514.5
				Stage 3	~521.0
			Terreneuvian	Stage 2	~529.0
				Fortunian	~538.8 ± 0.6

Supereonothem	Eonothem	Erathem	System	Numeric Age
				~538.8 ± 0.6
Precambrian	Proterozoic	Neoproterozoic	Ediacaran	~635
			Cryogenian	~720
			Tonian	1000
		Mesoproterozoic	Stenian	1200
			Ectasian	1400
			Calymmian	1600
		Paleoproterozoic	Statherian	1800
			Orosirian	2050
			Rhyacian	2300
			Siderian	2500
	Archean	Neoarchean		2800
		Mesoarchean		3200
		Paleoarchean		3600
		Eoarchean		4031 ± 3
	Hadean			4567

Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Ratified Subseries/Subepochs are abbreviated as U/L (Upper/Late), M (Middle) and L/E (Lower/Early). Italic fonts indicate informal units and placeholders for unnamed units. Previous versions and detailed information on ratified GSSPs are available at the website http://www.stratigraphy.org. The URL to this chart is provided below.

Numerical ages are subject to ongoing revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.

Most numerical ages are taken from 'A Geologic Time Scale 2020' by Gradstein et al. (2020), but some ages differ as provided by the relevant ICS subcommissions, with advice from the Timescale Calibration subcommission. These are approved by the ICS executive as the current consensus.

Chart drafted and maintained online by officers K.M. Cohen and N. Car. The chart is a product of collective work by all ICS members past and present.

Reference: The ICS international chronostratigraphic chart this decade. Episodes 2025; https://doi.org/10.18814/epiiugs/2025/025001

URL: https://stratigraphy.org/chart