This worksheet is about mud, grains of clay minerals mixed with water. Muds can form mudstones when they are tightly compacted together.

This lesson is inspired by research at Oxford University into Australian mudstone fifteen times older than the dinosaurs. Traces of oxygen, nutrients, and early life in the mudstone has helped entirely reshape our picture of evolution and how the Earth developed.

**Structures and Bonding**

Muds are fine-grained sediments made of minerals. The atoms of minerals are arranged in giant inorganic structures bonded via strong electrostatic forces; it takes a lot of energy to break these bonds, and they are mostly solids at room temperature with high melting and boiling points. So why doesn’t mud seem solid? Mud is a suspension of sediment particles in water.

Giant structures form lattices: a repeating array of atoms. The geometry of this arrangement of atoms determines the morphology (or shape) of the whole crystal. For example, atoms arranged in packs of six form hexagonal crystals, whereas atoms arranged in fours form cubic crystals.

“**Ball and stick**” models are useful for showing how the shapes of giant structures are made from arrays of single atoms.

Structure can also determine colour. The colour of a mineral depends on the identity of the elements in it and the geometry of their arrangement. This is because different faces of the crystal interact with light in different ways.

There are three kinds of giant structures: ionic, covalent, and metallic.

In ionic structures, such as magnetite, Fe₃O₄, metals donate electrons and non-metals accept electrons to form a pair of charged ions that attract.

In covalent structures, two non-metals share electrons, like silicon and oxygen in quartz, SiO₂.

In metallic structures, metals donate electrons to form positive ions surrounded by a delocalised electron sea.

**Your task: Eras of the Earth**

https://www.oxfordsparks.ox.ac.uk/content/ancient-mysteries-marvellous-mud
Match up the Eras of the Earth with their dates and the events that took place during this time.

<table>
<thead>
<tr>
<th>Era</th>
<th>Date Range</th>
<th>Events</th>
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</table>
| Neoproterozoic       | 66 million years ago - now | - Nuna supercontinent forms  
- Great Oxygenation event occurs – increasing the Earth’s oxygen  
- Eukaryotic life evolves |
| Mesoarchean          | 252-66 million years ago | - Believed to be the era in which the first life evolved  
- High pressure no-oxygen atmosphere  
- Earth’s crust develops |
| Mesoproterozoic      | 541-252 million years ago | - Cambrian explosion – the evolution of fish, amphibians and land animals  
- Coal beds are formed  
- Supercontinent Pangaea forms |
| Eoarchean            | 1000-541 million years ago | - Pangaea breaks up  
- Dinosaur populations boom, then big dinosaurs become extinct  
- Temperatures are high and sea levels low |
| Paeleoarchean        | 1600-1000 million years ago | - Photosynthesis evolves  
- Supercontinent Kenorland forms and breaks up  
- Earth begins to cool |
| Neoarchean           | 2500-1600 million years ago | - Supercontinent Vaalbara starts to break up  
- Earliest reefs form  
- Atmospheric carbon dioxide reaches pre-industrial levels |
| Cenozoic             | 2800-2500 million years ago | - Supercontinent Rodinia forms  
- Sexual reproduction evolves  
- Nuna supercontinent breaks up |
| Mesozoic             | 3200-2800 million years ago | - Earliest fossils of multicellular life  
- Rodinia breaks up  
- In a “snowball Earth” ice sheets reach the equator |
| Paeleoproterozoic    | 3600-3200 million years ago | - Himalayas form  
- Large mammals evolve  
- South America attaches to North America |
| Paeleozoic           | 4000-3600 million years ago | - Supercontinent Vaalbara forms |

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Your task: Through the Lens

1. Look up some common, semi-precious or precious minerals, and which metals lend them their distinctive colours.
2. Compare this to what you know about the colours of transition metals in solution using your text book or online revision materials. Do you see any correlations? Complete table 1.
3. Use a microscope to examine some mineral samples and record your observations in table 2. Include:
   - A scaled diagram of each mineral, showing key morphological features and including a scale factor of magnification.
   - Morphological observations: are the crystals more cubic, hexagonal, needle-like? Are the crystal shapes consistent throughout or not?
   - Colour observations: are the crystals shiny or matt? Is the colour consistent throughout, or does it vary?

<table>
<thead>
<tr>
<th>Metal</th>
<th>Colour in a mineral</th>
<th>Colour in aqueous solution</th>
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<tbody>
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<tr>
<td>Mineral</td>
<td>Scale diagram (including scale factor)</td>
<td>Morphological observations</td>
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<td>1.</td>
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<td>2.</td>
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X-ray Supermicroscope

X-ray diffraction is an analytical technique that can be used to identify structures. X-rays interact with matter just like light does – they can be reflected, absorbed, refracted, or diffracted.

When x-rays meet regular arrays of atoms, they are diffracted, like waves of water passing through a small hole. This means that the structure acts as a three-dimensional diffraction grating.

Diffracted x-ray beams leaving a crystal interfere with each other and add up. They either constructively or destructively interfere, giving “bright” or “dark” spots.

Your task: Interference

When waves interfere they add up. Can you add up the peaks and troughs of these waves to find the resultant wave?
**Your task: Diffraction Patterns**

Use a laser pen and piece of fabric to make a two-dimensional diffraction grating.

1. Shine a laser pen through a piece of gauzy fabric at a blank wall away from any people. Observe the pattern.
2. What happens if you use a different colour (or wavelength) laser pen?
3. What happens with wider or narrower weave fabric? Ask a friend to measure the distance between the centres of bright spots (be careful). This distance is inversely proportional to the spacings between atoms. What is its relationship to the wavelength of light?

**Fingerprinting Early Life**

Minerals can be made by geochemical reactions – some of which take place on very long timescales – but also by biological processes. Some bacteria **respire, digest, and synthesise minerals**. Scientists can tell by looking at rock morphologies which minerals were laid down by early life forms.

Every rock has a **unique x-ray diffraction “fingerprint”**, which depends on what it is made of and how its atoms are arranged. This is much like human suspect fingerprints at a crime scene.

One mineral, hydroxyapatite, $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$, only forms long fibres when it is made biologically. Finding fibrous hydroxyapatite crystals might indicate or “fingerprint” early life.

**Cycle for the respiration of iron by bacteria:**

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https://www.oxfordsparks.ox.ac.uk/content/ancient-mysteries-marvellous-mud
How do scientists know that the iron-respiring bacteria were from the Neoproterozoic era?

Scientists use isotopic labelling to date mineral samples in a field called geochronology. Knowing the decay constant of a radioactive isotope (λ) allows them to calculate its half-life, T_{1/2}. T_{1/2} is the time it takes for half of a radioactive isotope to decay away.

\[ T_{1/2} = \frac{ln(2)}{\lambda} \]

To calculate the age of a sample:

\[ P_t = e^{-\lambda t} \]

Where \( P_t \) is the fraction of the population that remains at time t.

The \(^{187}\text{Re}\) decay constant is \(1.666 \times 10^{-11}\) per year. Find:

1. The half-life of \(^{187}\text{Re}\).
2. The age in years of a sample of rock for which 98.7% of the \(^{187}\text{Re}\) isotopes remain.
3. Use your answer to explain why \(^{14}\text{C}\) dating is not used for the Neoproterozoic era. \(^{14}\text{C}\) has a half-life of 5730 years.

Your task: Find evidence of early life

Apatite reference spectrum

https://www.oxfordsparks.ox.ac.uk/content/ancient-mysteries-marvellous-mud
Sample spectrum 1

https://www.oxfordsparks.ox.ac.uk/content/ancient-mysteries-marvellous-mud
Sample spectrum 3

Data: Oxford University

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