Key Stage 5
Fingerprinting First Life

Student worksheet

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.

Your task: Eras of the Earth

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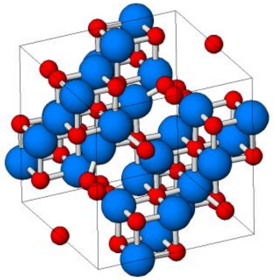
"**Ball and stick**" models are useful for showing how the shapes of giant structures are made from arrays of single atoms.

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.

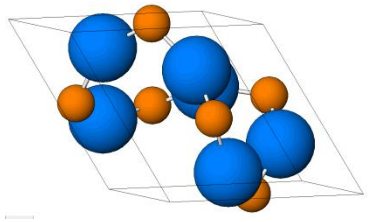
There are three kinds of giant structures: **ionic**, **covalent**, and **metallic**.

In **ionic** structures, such as magnetite, Fe_3O_4, metals donate electrons and non-metals accept electrons to form a pair of **charged ions** that attract.



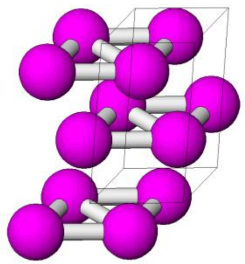
Magnetite

In **covalent** structures, two non-metals **share** electrons, like silicon and oxygen in quartz, SiO_2.



QuQuartz

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



ZinZinc

Images made using ATOMS68

Match up the Eras of the Earth with their dates and the events that took place during this time.

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

		• A large asteroid collides with Africa • Earliest fossilised bacteria

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 1

Metal	Colour in a mineral	Colour in aqueous solution

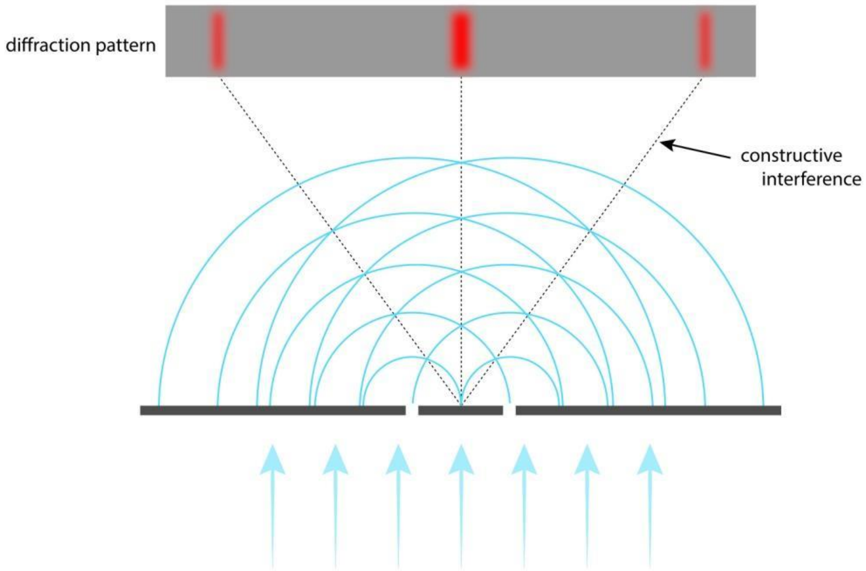
Table 2

Mineral	Scale diagram (including scale factor)	Morphological observations	Colour observations
1.			
2.			

3.			

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



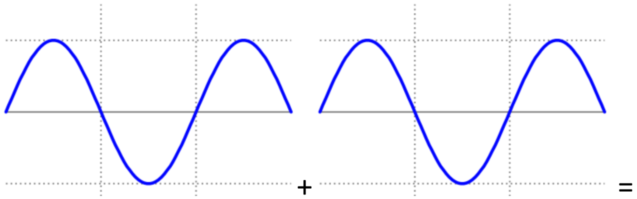
– they can be reflected, absorbed, refracted, or diffracted.

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**?



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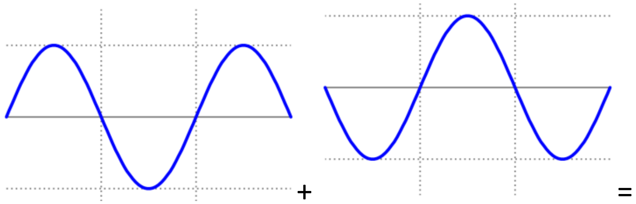
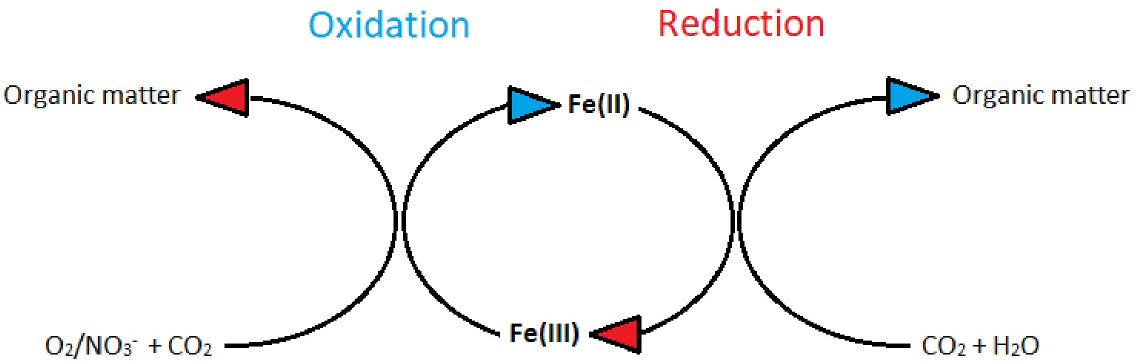


Your task: Diffraction Patterns

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



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.

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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, $Ca_5(PO_4)_3(OH)$, 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:

Your task

Compare the apatite reference spectrum to the Neoproterozoic sample spectra to search for evidence of early life. These are found on the next pages.

Extension: Radioactive Isotopic dating

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:

$$P_t = e^{-\lambda t}$$

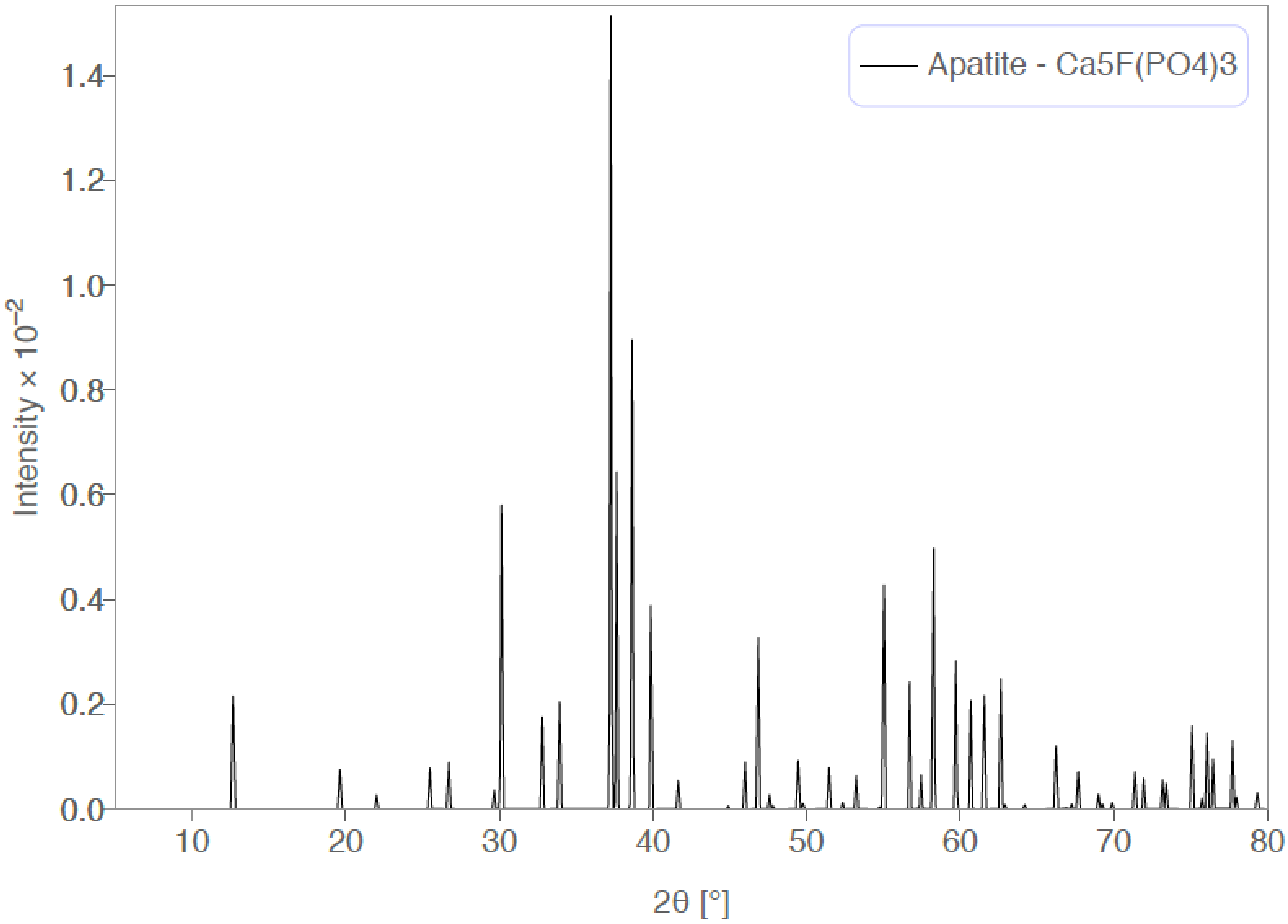
Where P_t is the fraction of the population that remains at time t.

The ^{187}Re decay constant is 1.666×10^{-11} per year. Find:

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

Your task: Find evidence of early life

Apatite reference spectrum



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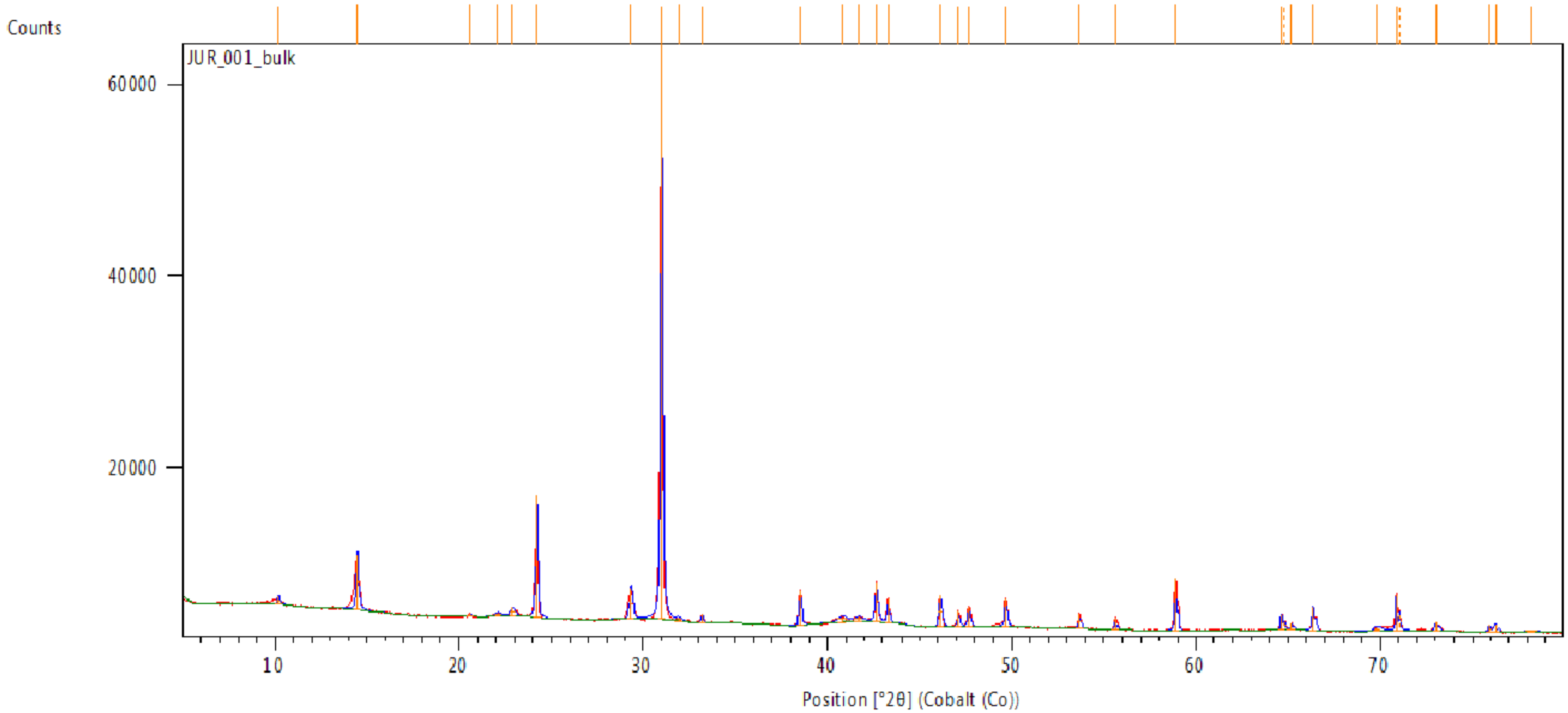
Sample spectrum 1



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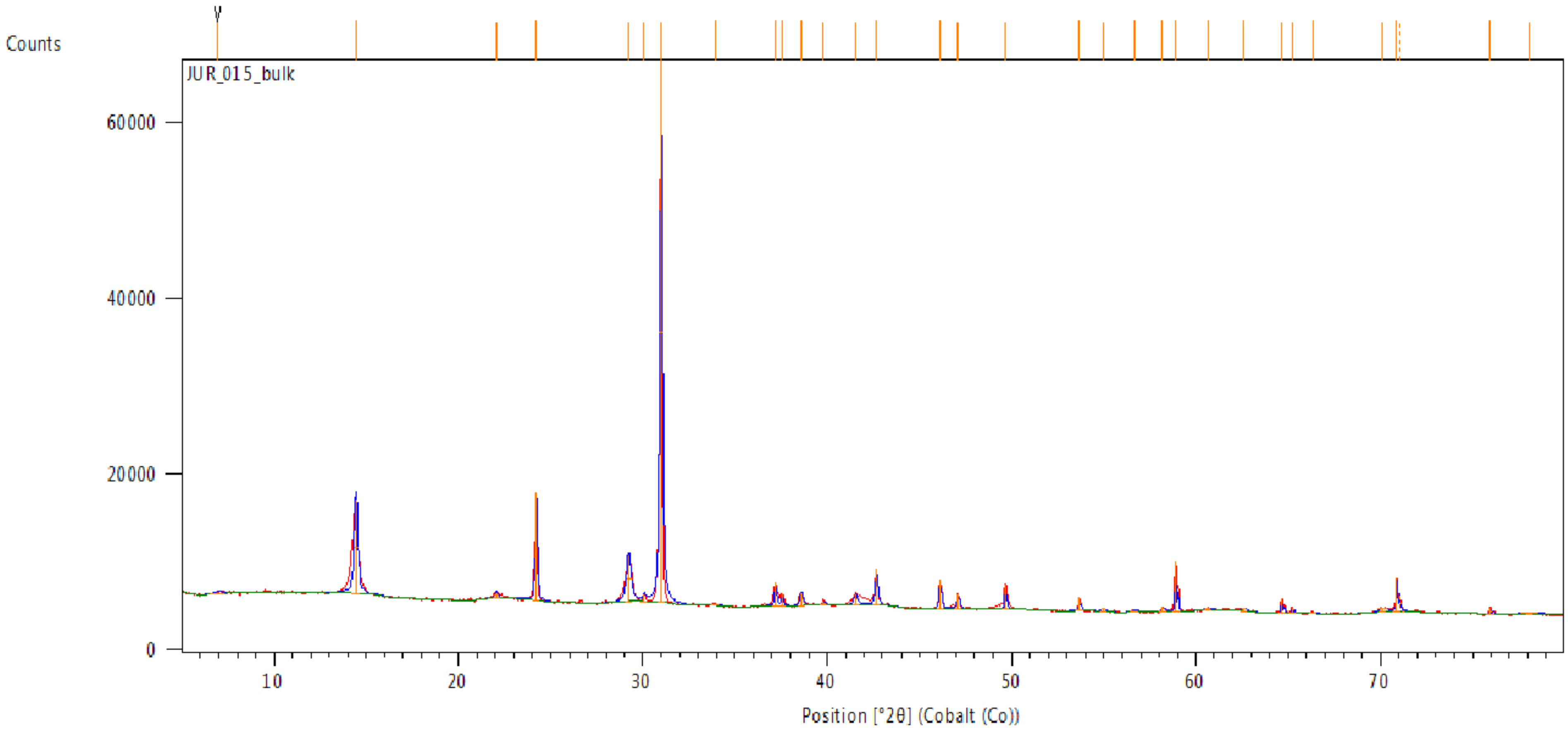
Sample spectrum 2



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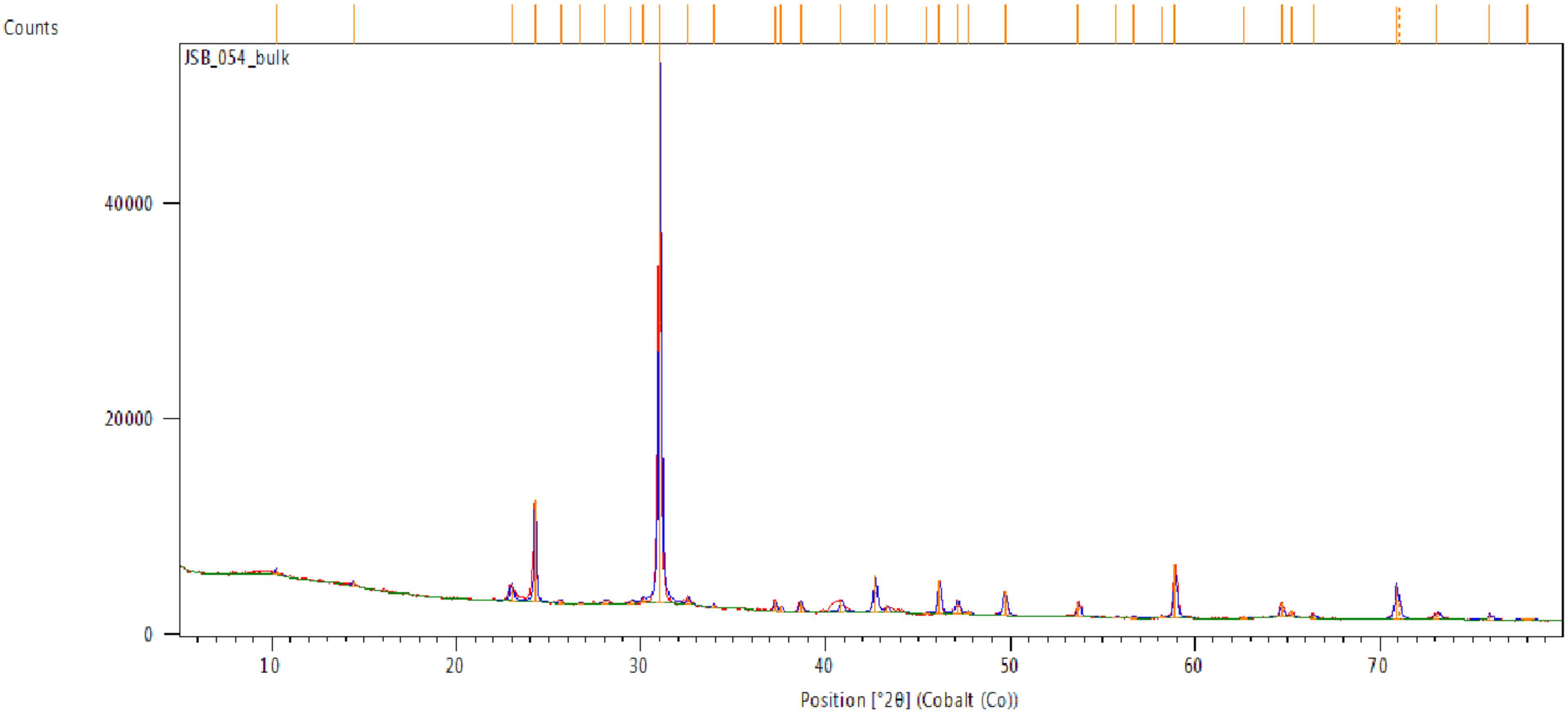
Sample spectrum 3



Data: Oxford University

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