Key Stage 4

Fingerprinting Mars Mud

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

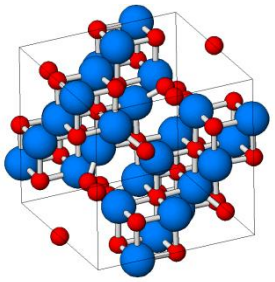
This lesson is inspired by research at Oxford University into Australian mudstone fifteen times older than the dinosaurs. Traces of oxygen, nutrients, and early life in the mudstone has helped entirely reshape our picture of evolution, how the Earth developed and could help us identify traces of early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

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.

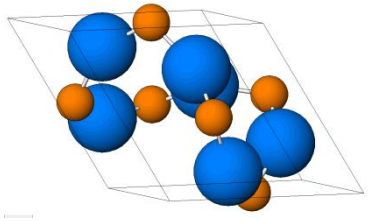
There are three kinds of giant structures: **ionic**, **covalent**, and **metallic**.

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.



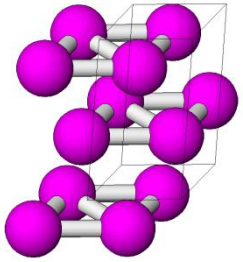
Magnetite

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



Quartz

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



Zinc

Images made using ATOMS68

Giant structures form **lattices**: a repeating pattern of atoms. Depending on the patterns they are arranged in, the whole mineral can have a different **morphology** (or shape). For example, atoms in long chains make long, thin, needle-like minerals. How does mud "transport" minerals from place to place? Discuss this with your neighbour and write or draw your ideas.

Your task: Through the Lens

Use a microscope or magnifying lens to examine some mineral samples. Are any of the minerals:

- Shiny
- Fibrous
- Consistent throughout
- Cubic/needle-like/hexagonal

...and, if so, which? Fill in the table with your observations.

Mineral	Observations
1.	
2.	
3.	

X-ray Supermicroscope

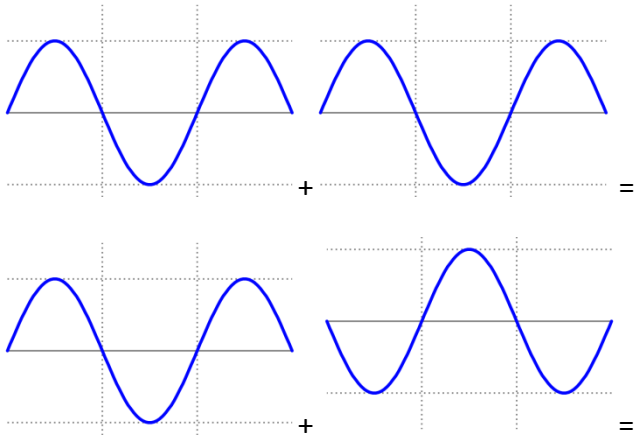
We use x-rays to probe the internal structures of muds from Mars to find out what minerals they are made of – a bit like a supermicroscope.

Have you ever noticed that some waves in the ocean are bigger than other waves? This sometimes happens because the crests of two waves meet, and add up to make a bigger crest. This is called **constructive interference**. Now imagine what would happen if the crest of a wave met the trough of another wave – there would be a subtraction, making a smaller wave (or even nothing), and that would be called **destructive interference**.

Constructive and destructive interference can happen with x-rays as well as ocean waves.

Your task: Add up the Waves

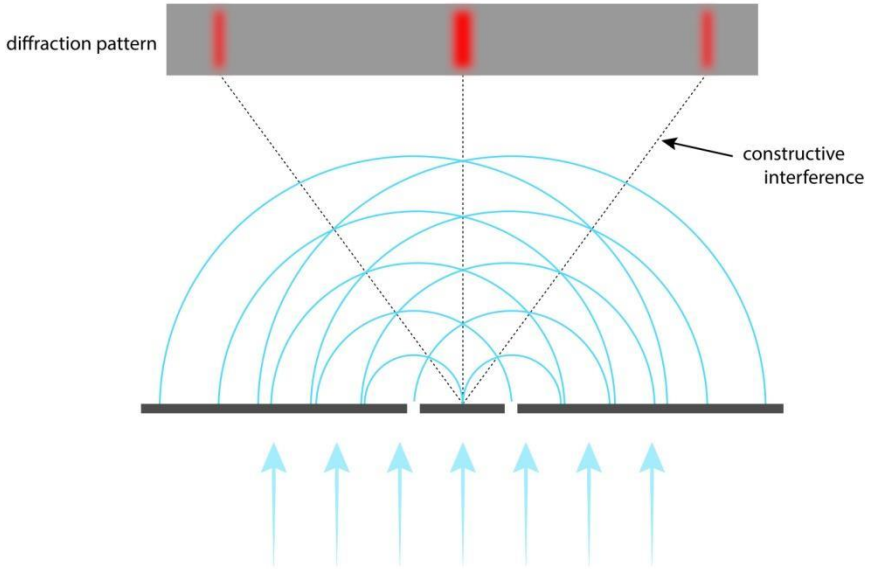
When waves interfere they add up. Can you add up the peaks and troughs of these waves to find the **resultant wave**?



Diffraction Gratings

When x-rays pass through rows of atoms, they are **diffracted**. This means they start spreading out in all directions.

When this happens at more than one place, the waves **interfere** or add up and make **interference patterns** of "bright" or "dark" spots. Every structure has a unique interference pattern, which can be used to "**fingerprint**" the structure like human suspect fingerprints at a crime scene.

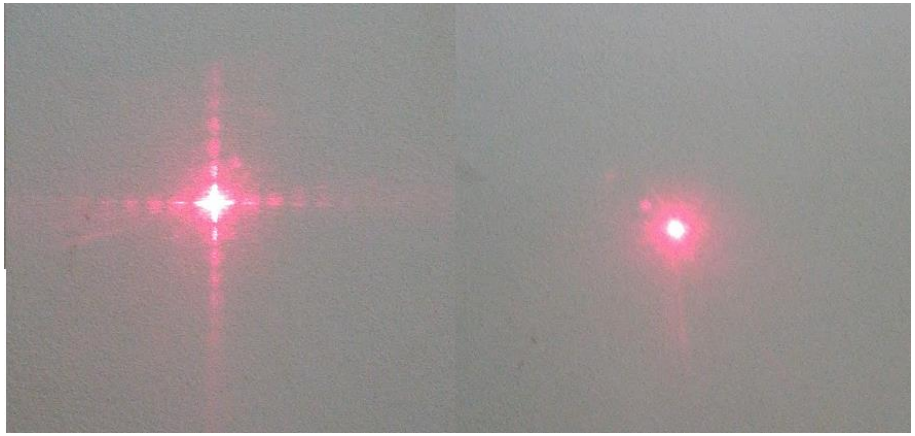


Your task: Laser pen diffraction

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. Draw the pattern.

Compare your pattern to these two images. Which is the image through the fabric?



2. How could you **extend** this scientific investigation to learn more about diffraction patterns?

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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.

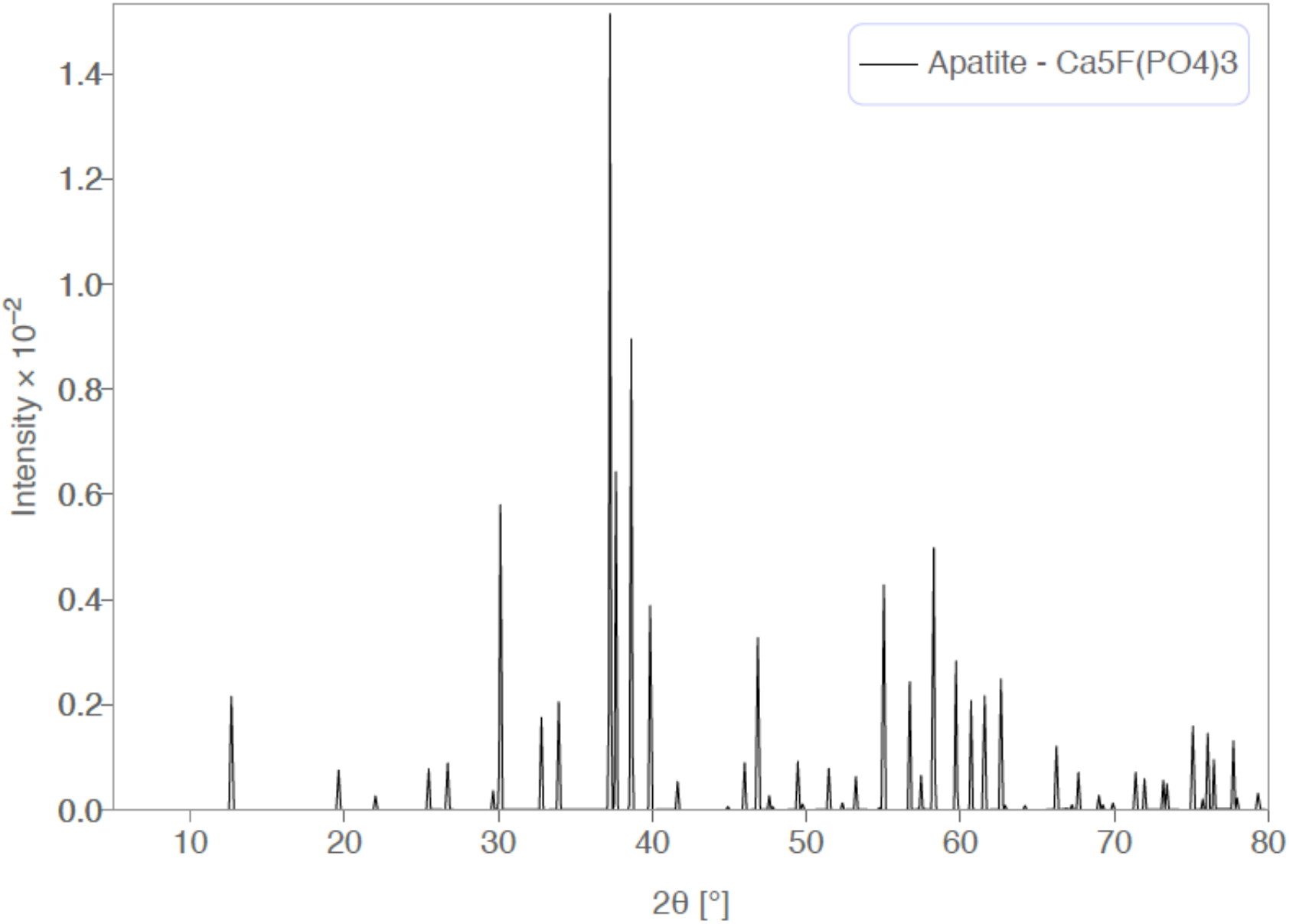
One mineral, hydroxyapatite, $Ca_5(PO_4)_3(OH)$, only forms long fibres when it is made biologically. Finding fibrous hydroxyapatite crystals might indicate or "fingerprint" early life.

Your task

A Mars Rover has sent back some x-ray diffraction patterns of muds on Mars (these are found on the next pages). Compare them to the reference spectrum for apatite. Can you find any evidence that there could be life on Mars?

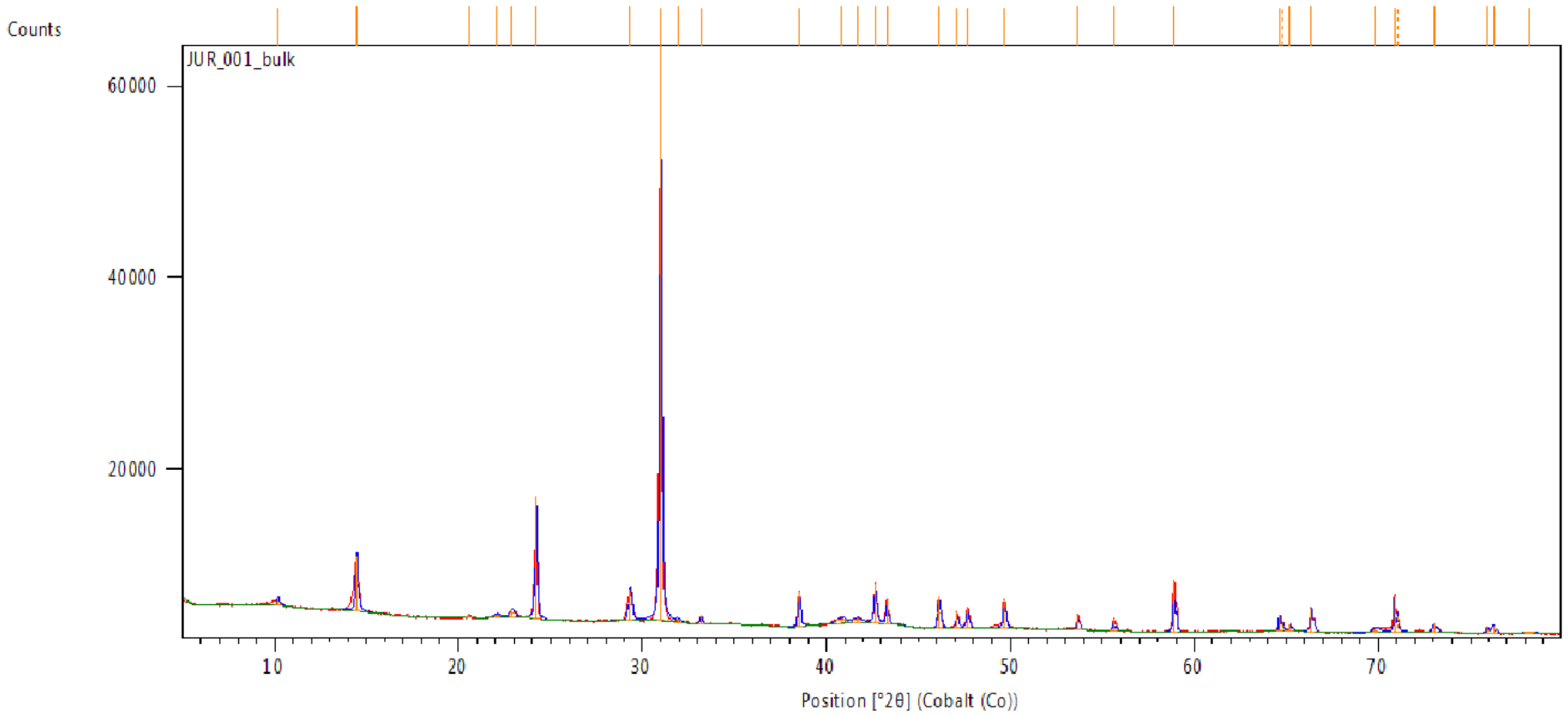
Your task: Find evidence of Martian life

Apatite reference spectrum



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

Sample spectrum 1



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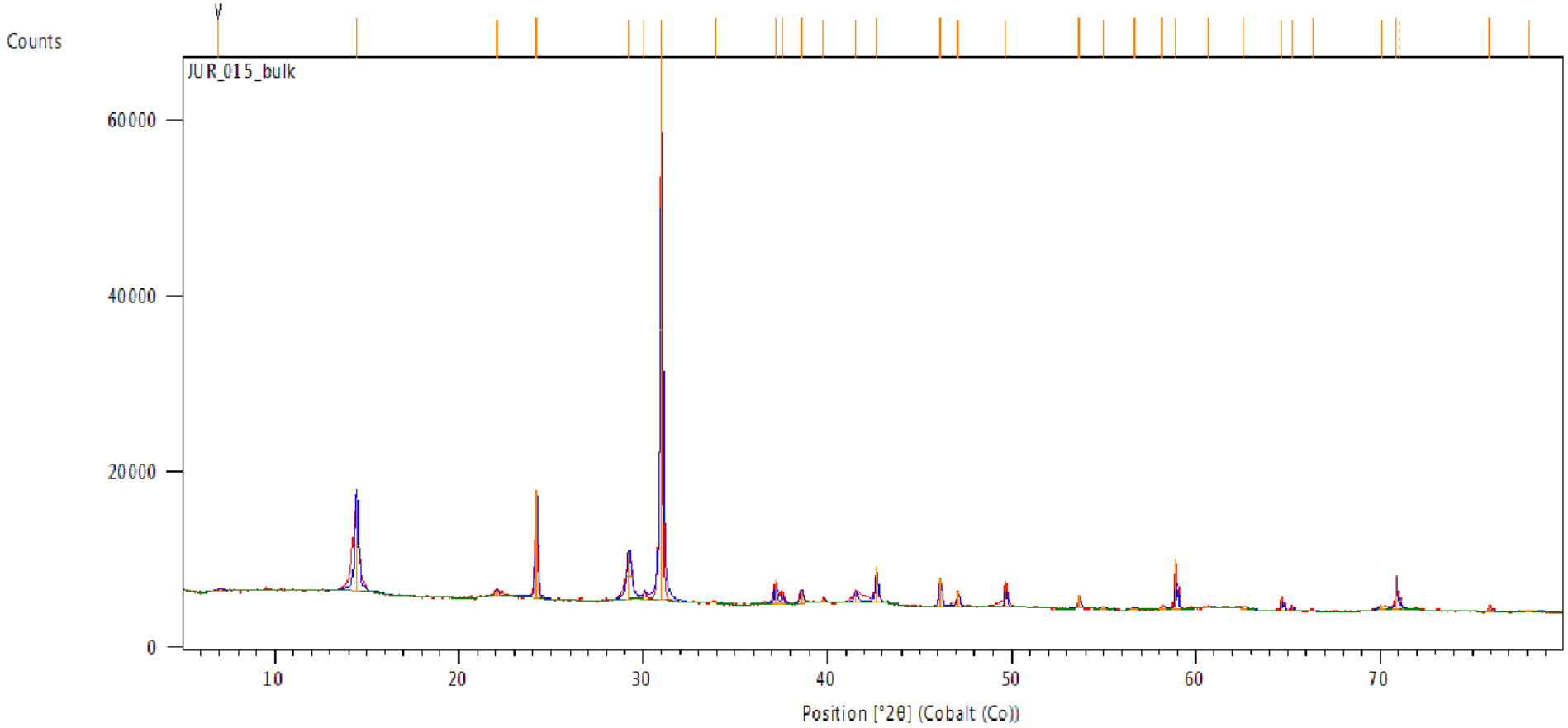
Sample spectrum 2



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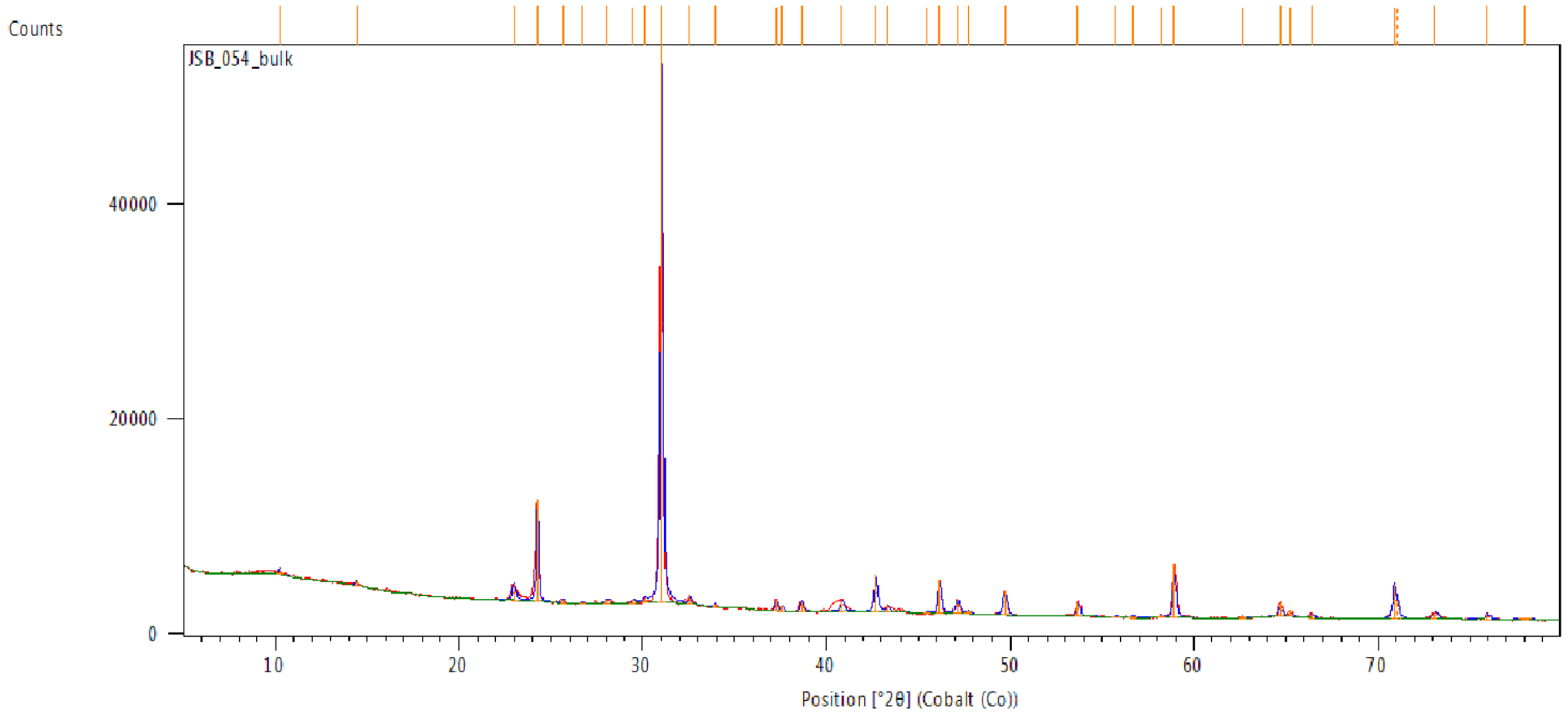
Sample spectrum 3



Data: Oxford University

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