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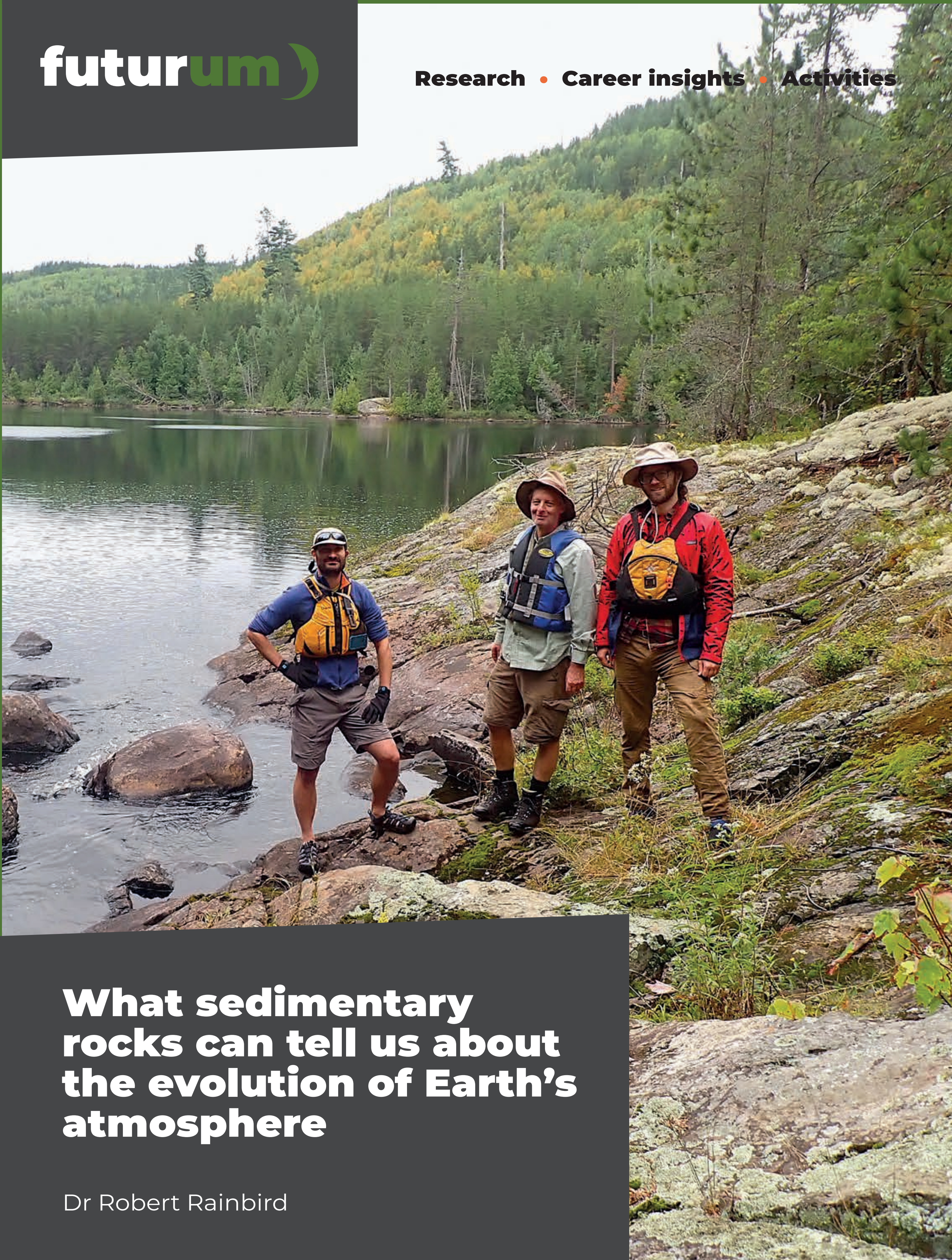

What sedimentary rocks can tell us about the evolution of Earth's atmosphere

Dr Robert Rainbird

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What sedimentary rocks can tell us about the evolution of Earth's atmosphere

Rocks have a lot to tell us about the history of our planet. Geologists study rocks to identify the clues they hold and decipher the answers they reveal. **Dr Robert Rainbird**, a sedimentologist at the **Geological Survey of Canada**, is examining ancient sedimentary rocks in the Temagami region of northeastern Ontario to look for evidence of the Great Oxygenation Event – the time at which Earth's atmosphere first became oxygen-rich, setting the stage for the emergence of early life.

Dr Robert Rainbird

Research Scientist, Geological Survey of Canada, Ottawa, Ontario, Canada

Adjunct Professor, Department of Earth Sciences, Carleton University, Ottawa, Ontario, Canada

Fields of research
Sedimentology, stratigraphy, Precambrian Earth history

Research project
Studying ancient sedimentary rocks to understand the Great Oxygenation Event

Funders
Natural Resources Canada (NRCan), Natural Sciences and Engineering Research Council of Canada (NSERC)

Talk like a ...
sedimentologist

Conglomerate — sedimentary rock composed of sediment of varying sizes, from fine sand to large pebbles

Great Oxygenation Event (GOE) — a period in Earth's history (around 2.3 to 2.4 billion years ago) during which oxygen levels in the atmosphere rose to the point at which metals could be oxidised (also known as the Great Oxidation Event)

Oxidise — to chemically add oxygen atoms to a substance (e.g., rusting of iron)

Radioactive decay — the process by which a radioactive element (e.g., uranium) emits radioactive energy as it is converted into another element at a predictable rate

Sedimentary rock — rock that is formed when sediment (weathered pieces of older rock) is eroded, transported, deposited and then lithified (compacted and cemented into solid rock)

Sedimentology — the branch of geology that studies the characteristics and formation of sedimentary rocks

Zircon — a mineral that contains trace amounts of uranium and so can be used for dating rocks

Two and a half billion years ago, the Earth's atmosphere was largely oxygen-free. Life primarily consisted of single-celled microbes that did not require oxygen to live. The first photosynthesising bacteria generated oxygen as a by-product, but this oxygen rapidly reacted with other elements in the ocean and rocks before it could escape into the atmosphere. It took a long time before oxygen built up in the atmosphere, allowing more complex life to evolve.

Given that the Great Oxygenation Event (GOE) occurred several billion years ago, it is very difficult to pinpoint exactly when, how or why it occurred. At the Geological Survey of Canada, Dr Robert Rainbird is studying sedimentary rocks formed before, during and after the GOE to learn more about this monumental event in Earth's history and to test a hypothesis that the GOE was triggered by a change in the Earth's climate.

Searching for clues

"Evidence for the GOE is found in sedimentary rocks that were deposited between 2.4 and 2.3 billion years ago," explains Rob. "However, there are only a few places on Earth where rocks of this age are well-preserved, exposed and accessible." One of these areas is the Temagami region of northeastern Ontario. Rob and his team conduct fieldwork there to examine the rocks for clues and they collect samples to take back to the lab. "We begin by observing fresh (i.e. not covered by lichen) exposures of rock, mainly along roadsides and lakeshores,"

Rob and his colleague examine lakeside sedimentary rocks by canoe

he explains. The team examines characteristics of the rocks, such as colour, grain size, type of layering and any other distinctive sedimentary structures.

In the lab, the team conducts further analyses of the samples they collected. "We use a diamond saw to cut an extremely thin slice of rock, only 0.03 mm thick, which we examine under a microscope to observe the texture and composition of the sedimentary grains," says Rob. "We also crush the rock to separate out certain minerals (e.g., zircon), or we grind it to a powder for geochemical analysis."

> "**Sedimentary rocks have characteristics that... give us clues about the type of environment and climate that existed at the time of deposition.**"

Connecting the dots

Piecing together the nature of the GOE from rock samples requires three key pieces of information: when the rocks were formed, how they were formed, and oxygen levels during their formation. Rob uses different techniques to investigate each of these factors.

To date the rocks, the team analyses the composition of the mineral zircon. Zircon contains small amounts of uranium, which radioactively decays into lead at a very predictable rate. "This means that by measuring the amounts of uranium and lead in a zircon grain, we can determine how old the grain is and, therefore, the age of the rock that it came from," explains Rob.

Understanding how sedimentary rocks were formed involves observing features of the rocks and interpreting the environmental conditions that caused these features. "Sedimentary rocks have characteristics that can tell us about the type of flow that deposited them (e.g., river or glacier), as well as the strength and direction of the flow," explains Rob. "This gives us clues about the type of environment and climate that existed at the time of deposition."

For example, glaciers can carry large pebbles and boulders within the ice while also grinding sediment at their base to very fine powder. This means sedimentary rocks produced by glacial deposition often consist of particles ranging in size from less than 0.1 mm to over 20 cm (i.e., conglomerate). In contrast, sedimentary rocks formed by deposition in a fast-flowing river typically consist of sand grains of roughly equal size (i.e. sandstone), as the fast current will carry away the smaller grains.

Finally, Rob investigates whether each rock sample was formed before or after the atmosphere became oxygen-rich by looking to see if it contains minerals that form in the presence or absence of oxygen. "For instance, pyrite (a form of iron sulphide; FeS_2) breaks down when exposed to oxygen, so won't be found in rocks formed after the GOE," he explains. "On the other hand, haematite (a form of iron oxide; Fe_2O_3) only forms under oxidising conditions, so will only be found in rocks formed after the GOE."

Discoveries so far

The oldest rocks Rob and the team have studied are grey and green sandstones and conglomerates, which contain sand grains and pebbles of the mineral pyrite, indicating they were deposited before atmospheric oxygen was present. Some conglomerates display structures suggesting they were deposited by glacial processes during a cold climate. In contrast, the overlying (i.e. younger) rocks that Rob studied are sandstones with structures and mineral compositions that suggest they were deposited in rivers under a warm and humid climate. Some of these sandstones are red because they contain haematite, composed of oxidised iron, suggesting they formed in an oxygen-rich atmosphere.

"Our work suggests that, contrary to its name, the Great Oxygenation Event was not an instantaneous event, but rather a gradual process occurring over many tens of millions of years," concludes Rob. "And our results support a hypothesis that atmospheric oxygen levels had increased to a level capable of oxidising iron minerals by 2.3 billion years ago. After a long, cold glacial episode, sediments were deposited under warm, humid conditions, suggesting a possible link between climate warming and atmospheric oxygenation."

About *sedimentology*

Sedimentary rocks provide clues to Earth's history and, by studying them, sedimentologists can learn about past climates, environments and life. Sedimentary rocks are made from sediments that have been weathered from older rocks. "Weathering is largely controlled by the climate (it occurs more quickly in warmer and wetter climates) and the minerals in the rock being weathered (harder minerals such as quartz are less easily weathered than soft minerals such as feldspar)," explains Rob. "So, by looking at the texture and composition of a sedimentary rock, we can make inferences about the climate that existed at the time the sediment was generated." Sedimentary rocks are also a source of information about prehistoric life. Some sedimentary rocks contain fossils, which can tell us about which plants and animals lived in the region when the rock was deposited, what the environment was like and the age of the rock.

The joys and challenges of fieldwork

Working as a sedimentologist can include exciting fieldwork in far-flung places. "I've spent most of my career studying Precambrian rocks (older than 540 million years) in the Canadian Arctic," says Rob. "There aren't many roads, so accessing the rocks I need to study can be a challenge. This often involves flying by helicopter, hiking across the tundra or canoeing around lakes."

"If you like working outdoors, a career in geology could be for you!" continues Rob. However, fieldwork also has its challenges. "Days can be long, and you need to be prepared to deal with bad weather and basic accommodation." You might find yourself working in close quarters with other people (including other geologists as well as non-scientists, such as drill rig workers) for long periods of time, so good social skills and an ability to engage with a range of personalities are important. "Above all, you must be an inquisitive person with good imagination," says Rob.

Pathway from school to *sedimentology*

At high school, Rob's favourite subject was physical geography, which introduced him to the processes that affect the Earth's surface. Knowledge of the modern processes that influence the Earth are vital for understanding ancient environments in which sedimentary rocks were formed.

Other useful subjects to study at high school include physics, chemistry, biology, mathematics, and – if available – Earth science or environmental science.

Sedimentology and its sister discipline stratigraphy (the study of rock layers) are branches of geology, so at university, consider a degree in geology, Earth science or physical geography.

To specialise in sedimentology/stratigraphy, Rob recommends seeking graduate studies with a professor who specialises in the study of sedimentary rocks, has a good reputation for working with students and publishes well-cited research.

Team members conducting fieldwork in Temagami

Explore careers in *sedimentology*

Traditionally, most sedimentologists worked in the oil and gas industry, using their skills to identify oil and gas reservoirs. This could involve collecting and analysing rock samples on oil rigs or examining geophysical information using sophisticated computer software.

Today, some sedimentologists use these same skills in the 'carbon capture and storage' industry, to locate rocks that could store carbon dioxide created by industrial activity to prevent it being emitted into the atmosphere.

Field sedimentologists, like Rob, often work for government geological surveys where they conduct fieldwork-based research to improve understanding of the country's geology and geological resources.

"Environmental geoscience is a rapidly growing career area," says Rob. "Sedimentologists can play their part in this field by studying ancient climate cycles to help build understanding of current climate change."

EarthLinks, an initiative by the Canadian Geoscience Education Network, provides a vast array of education, outreach and career advice resources on many geoscience disciplines: **www.cgenarchive.org/earthlinks.html**

Carleton University has an active Earth Sciences outreach programme that runs school visits, summer camps, and geoheritage days: **www.earthsci.carleton.ca/outreach**

The Geological Society has created an interactive geology careers guide: **www.geolsoc.org.uk/geologycareerpathways**

Meet *Rob*

As a teenager, I loved listening to and playing music, and participating in sports and outdoor recreation. My dad was an outdoorsman who took our family on camping trips all over North America. I really enjoyed these adventures, especially if I could go fishing!

My university professors inspired me to become a geologist. I went to university to study biology, but after a fantastic introductory geology course in my first year, I switched my major to geology. Then, in my second year, my field geology professor introduced me to sedimentology, and I went on to study the sedimentary rocks of the Temagami region under his supervision. He is now in his nineties and remains my inspiration!

The best thing about being a geologist is the fantastic travel opportunities – I've been to remote regions all over northern Canada that most people will never get to see. However, the preparatory logistics for a field expedition are highly challenging – my last Arctic expedition was only three weeks long but took almost two years to organise!

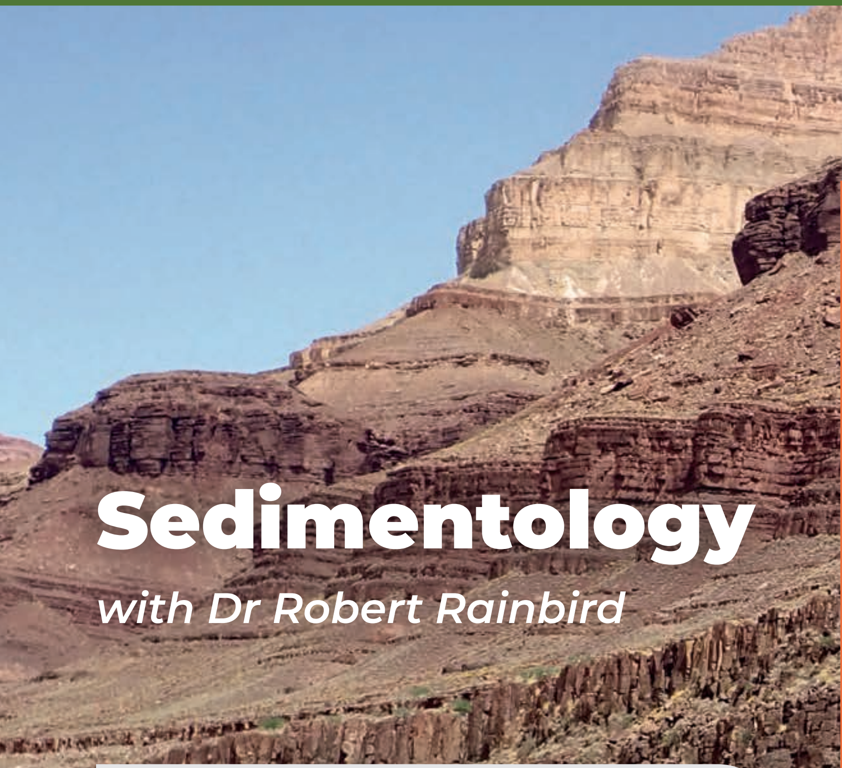
My most vivid fieldwork memory is flying over the Canadian Arctic in a helicopter. I had a bird's-eye view of some of the most breathtaking landscapes imaginable. During my nearly forty years of fieldwork, I have had the great pleasure of spending time with many wonderful people, including other geologists, Indigenous community members, students and pilots. I have also had the privilege of mentoring young graduate students and watching them grow into successful geoscientists.

In my free time, I enjoy winter sports, including ice hockey, curling and cross-country skiing. In the summer, I go hiking and on canoe-camping trips with my friends. I still love music, attending live concerts and playing bass guitar as a hobby.

Rob's *top tips*

1. Find work that is related to your interests. Don't be tempted to take a higher-paid position that you don't enjoy.

2. There's no substitute for practical experience to learn something. I didn't really understand the geological concepts I was taught in the classroom until I was able to see them in the field.



Sedimentology

with Dr Robert Rainbird

Talking *points*

Knowledge

1. What was the Great Oxygenation Event (GOE) and when did it occur?

Comprehension

2. How and why does Rob conduct geological fieldwork in the Temagami region?
3. How and why does Rob examine zircon grains in sedimentary rocks?

Application

4. Do you think Rob looks at fossil evidence to learn more about the GOE? Why or why not?
5. What questions would you ask Rob to learn more about the realities of geological fieldwork?

Analysis

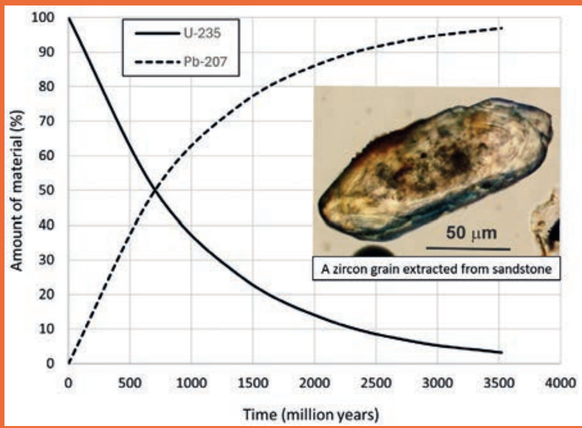
6. Why do different types of sedimentary environments (e.g., rivers, glaciers) lead to different characteristics in sedimentary rocks? And why is it important to study the characteristics of sedimentary rocks?

Evaluation

7. Giving examples, how do you think that learning more about the GOE can inform our understanding of, and predictions for, modern climate change?
8. Why do you think that today's sedimentologists are seeking a wider range of careers beyond the oil and gas industry? And how do you think they can contribute to the growing field of environmental geoscience? What other career opportunities do you think will be available for sedimentologists in the future?
9. To what extent would you like to take part in geological fieldwork? What aspects do you think you would find enjoyable, and what would you find challenging?

Activity

Zircon contains uranium-235 (U^{235}) which decays into lead-207 (Pb^{207}) with a half-life of 704 million years. This means that after 704 million years, half of the U^{235} in a zircon grain will have decayed into Pb^{207}. Using the graph below, what is the age of a zircon grain in which 60% of the original U^{235} remains and 40% has decayed into Pb^{207}?



Use information from Rob's article, the graph above and any further research to describe a hypothetical sedimentary rock.

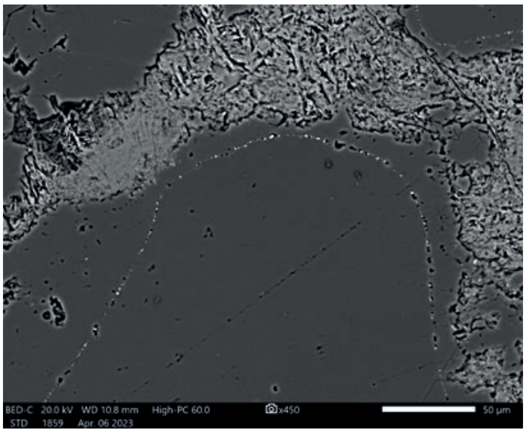
First, decide when your rock formed. Research to find out what climatic, environmental and atmospheric conditions existed at that time, and what life existed. Then, based on this knowledge, consider what characteristics a sedimentary rock formed under these conditions would have. Your rock description could include details such as rock colour, grain size and variation, grain shape, minerals present, amount of original U^{235} remaining in zircon grains, types of fossils (if any), and sedimentary structures in the rock (e.g., cross-bedding, ripple marks). You might need to conduct further research into how these characteristics relate to specific sedimentary conditions and environments.

Once you have written your rock description, swap with a classmate and interpret their description to discover when and under what conditions their hypothetical rock was formed.

More *resources*

- This article from the US Geological Survey gives an overview of different techniques that geologists use to date rocks: **www.usgs.gov/observatories/yvo/news/a-beginners-guide-dating-rocks**

- This article gives an interesting insight into the history of the Geological Survey of Canada, where Rob works as a research scientist, through 175 intriguing objects: **www.science.gc.ca/site/science/en/educational-resources/history-geological-survey-canada-175-objects**



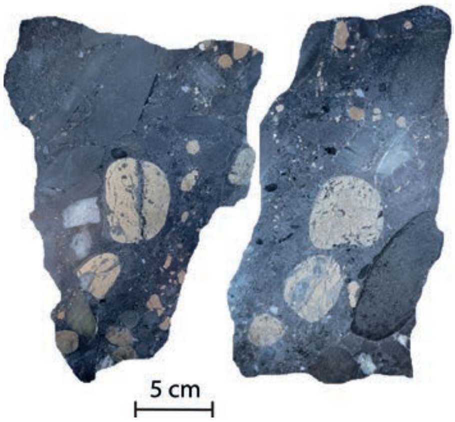


Photo *montage*

Top row: *A member of Rob's team examines the Earth's oldest red sandstone*

Middle row: ***Left:*** *A microscope image of a very thin slice of red sandstone showing tiny haematite dust grains (bright spots) surrounding a quartz sand grain (dark grey) - haematite (iron oxide) preservation suggests oxidising conditions prevailed at the time of deposition*

Centre: *A polished slab of pyrite pebbles in conglomerate that formed before the GOE - pyrite (iron sulphide) preservation suggests reducing conditions prevailed at the time of deposition*

Right: *Rob conducts fieldwork by canoe to access remote study regions, like Temagami*

Bottom: *Red sandstone that was deposited after the GOE*

+44 117 909 9150
info@futurumcareers.com
www.futurumcareers.com

futurum

Carleton University

Canada Geological Survey Commission Géologique 1842

NSERC CRSNG

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