A search for primary evidence of Earth’s ancient atmosphere and climate

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Robert Rainbird, a research scientist working for the Geological Survey of Canada, a division of Natural Resources Canada, looks at the geological evolution of Earth’s ancient atmosphere and climate

What did Earth look like two and a half billion years ago? When did our atmosphere and oceans become oxygen-rich? Did oxygenation occur rapidly or via incremental oscillations over millions of years? These questions have been debated by scientists for decades because of their implications for the evolution of early life on Earth. Through their research, Dr Robert H. Rainbird and his team at the Geological Survey of Canada and Carleton University (Ottawa) seek to answer these questions by investigating rocks from an ancient sedimentary basin north of Lake Huron in Ontario.

The Earth, Billions of Years Ago

Earth did not immediately become the blue and green planet we know immediately after it formed, more than four and a half billion years ago. It would take another two billion years before Earth’s ancient atmosphere started to accumulate oxygen and eventually support the multicellular life that filled the planet’s oceans and landmasses.

What the Earth looked like during this process of atmospheric and oceanic oxygenation – called the Great Oxidation Event (aka the GOE) – has been the source of vigorous scientific debate over the last four decades. Scientists are not sure exactly when the GOE occurred, or how long the process took. This is due to the difficulties associated with studying and reconstructing the environments that existed between one and two and a half billion years ago, from the evidence that has survived the ravages of time.

Was it a swift and irreversible change, such as a tipping point once the oxygen levels reached a certain level? Or did the changes in atmospheric oxygen take 100s of millions of years to become a permanent and prominent fixture of the Earth?

These questions have driven the career of research scientist Robert Rainbird from the Geological Survey of Canada and Carleton University. He has spent the past 40 years researching sedimentary layers (or strata) that were deposited during the earliest of the geological periods – the ‘Precambrian’ – which spanned the first four billion years of Earth’s 4.6-billion-year history.

Dr Rainbird's research centres predominantly on Proterozoic (2.5-0.5 billion-year-old) sedimentary basins in Canada. However, he has extended his research to sedimentary rocks of that age that are on continents that may have been attached to Canada during this time.

These sedimentary basins, filled by successive sedimentary strata, provide a record of the environments that existed while the sediments were being deposited. The sedimentology of the strata yields useful information about the climate, positions and movements of the planet's landmasses, life that existed at the time through fossils, and the oceanic and atmospheric conditions.

Dr Rainbird's team also studies the sedimentary strata by analysing their chemical and biochemical components using advanced analytical techniques.

Sedimentary rocks reflect tectonic processes

In their current research, Dr Rainbird and his team focus on a succession of sedimentary strata called the 'Huronian Supergroup' (aka the Huronian), well exposed in an area north of Lake Huron in Ontario, Canada. These rocks represent one of the most complete, best preserved, and most representative of its time period anywhere on Earth, and yet we still have a limited understanding of them.

By understanding the history of how and when sediments were deposited, Dr Rainbird's team aims to relate the 'plate tectonics' – or movements of the Earth's crust – during the period that led to the formation and break-up of the planet's first supercontinent. This information is foundational for scientists to understand how the Earth's climate has changed over time and how life began, evolved, and appeared and disappeared across the ages.

The team achieves this by establishing the age of tiny mineral (zircon) grains in sandstone, which tells us the age of the rocks from which the sand grains were derived by weathering. If the source region of the zircon grains can be established, it can also tell us whether the sandstone was derived locally or from far away – giving us further clues about the proximity of tectonic processes acting at the time.

Ultimately, Dr Rainbird and his team plan to compare the tectonic processes recorded in the sedimentary basins of Canada with those recorded in basins of a similar age on other continents, to develop an integrated and global correlation of these processes.

Impacts of the Great Oxidation Event

Dr Rainbird and his team are also looking at the Huronian for clues about Earth's ancient atmosphere and climate by mapping the distribution of the sedimentary strata and investigating the environmental conditions in which these layers were deposited.

By combining established techniques in field sedimentology with cutting-edge laboratory procedures, Dr Rainbird and his team can accurately date and chemically fingerprint the rocks. This will allow the researchers to correlate these sedimentary layers and the environmental conditions present at the time of deposition more accurately than ever before.

The source of atmospheric oxygen is generally thought to be a result of photosynthesis. Through the early Precambrian – called the 'Archean Eon' – it appears that oxygen sinks, particularly in the oceans, far outweighed the sources of oxygen. Ultimately, this state shifted in favour of oxygen accumulation at some time beginning approximately 2.5 billion years ago.

Recent studies have revealed that, after the GOE, atmospheric oxygen rose briefly, then declined, and stayed at relatively low levels for more than a billion years. Gaining an understanding of the conditions over this period could provide clues about the drivers behind these oxygenation changes.

Climate change, glaciations and atmospheric oxygenation

Sediments deposited during Earth's history provide a record of periods of 'glaciation' – cooler periods when glaciers covered much of the planet's surface. Dr Rainbird and his research team aim to use their findings to determine the timing and duration of three, possibly global-scale, glaciations preserved within the Huronian strata. This could provide an opportunity to compare these ancient glaciations with more contemporary glaciations recorded elsewhere on Earth, contributing to our understanding of the climatic conditions during and between glaciations.

One of the big questions Dr. Rainbird and his team is seeking to answer is: was the GOE an abrupt "event" or a protracted "episode" lasting 100s of millions of years? If the former,
Dr Rainbird may be able to link it with one or all of the three of the Huronian glaciations, providing further clues about the nature of the oxygenation process. Comparisons with correlative sedimentary successions in other regions, such as the Transvaal Supergroup in South Africa, could inform possible linkages of the GOE with so-called 'snowball Earth' glaciations – during which the planet was almost entirely covered in ice.

Understanding chemical anomalies to reduce misinterpretation

Advances in measuring the chemical composition of sedimentary rocks have progressed to a level that we are able to identify and measure anomalies in the ancient atmosphere and stratigraphic record with a high degree of accuracy. However, our understanding of the conditions and processes that give rise to such chemical anomalies has not kept pace with technological advancements, and thus we run the risk of misinterpreting our findings.

Recognising this gap, much of Dr Rainbird's current research focuses on establishing the environments during and after the sediments were deposited. This will allow researchers to determine whether chemical anomalies are a product of environmental conditions during deposition, or from chemical processes acting on the sediments after they were deposited (i.e. alteration).

Dr Rainbird's current research will provide us with new and better understanding of Precambrian Earth's evolution – encompassing planet-defining events such as the origin of life, the evolution of multi-celled organisms, and fundamental global changes in the climate, atmosphere, oceans, and the former configuration of landmasses.

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