Early Earth Magnetism: Exploring the role of Earth's magnetic field in atmospheric evolution

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Key words:	Early Earth, Planetary habitability, Great Oxidation Event, Atmospheric Escape, Paleomagnetism
Research theme(s):	• Geophysics and Geodynamics • Planetary Evolution and Materials
Eligible courses for this project:	• DPhil in Earth Sciences • Environmental Research (NERC DTP)

Overview

Earth's magnetic field is often included as a key planetary property for its habitability. This is because it is thought to protect Earth's surface from harmful cosmic radiation, and prevents the atmosphere from being eroded by the solar wind[1]. However, some recent studies have demonstrated that for certain magnetic field strengths, a planetary magnetic field can enhance atmospheric escape[2]. We know that Earth's atmospheric composition has changed drastically over time, particularly during the Great Oxidation Event (GOE)[3]. It is now thought that the oxidation of Earth could have, in part, been caused by the loss of hydrogen from the atmosphere[4,5]. This critical event may have been key to Earth's sustained habitability: when life first originated it required reducing conditions[6], whereas atmospheric oxygen is key for the survival of life today.

The oxidation of Earth via hydrogen escape may have been assisted by Earth's magnetic field. The weaker the field, the greater the extent of hydrogen loss[2]. However, the whole rock record of Earth's magnetic field prior to the GOE is poorly constrained[7]. In this project, 2.9 – 4.4 Ga terranes will be sampled across Canada. The paleomagnetism of collected samples will be measured to determine the strength of the ancient magnetic field. Extracting reliable paleomagnetic signals from such ancient samples is highly challenging. The project will pioneer new methods to investigate paleomagnetic signals in metamorphic rocks, and evaluate how paleomagnetic behaviour varies with metamorphic grade.

Results will be used to test current atmospheric escape models, and estimate the degree of hydrogen escape prior to the GOE.

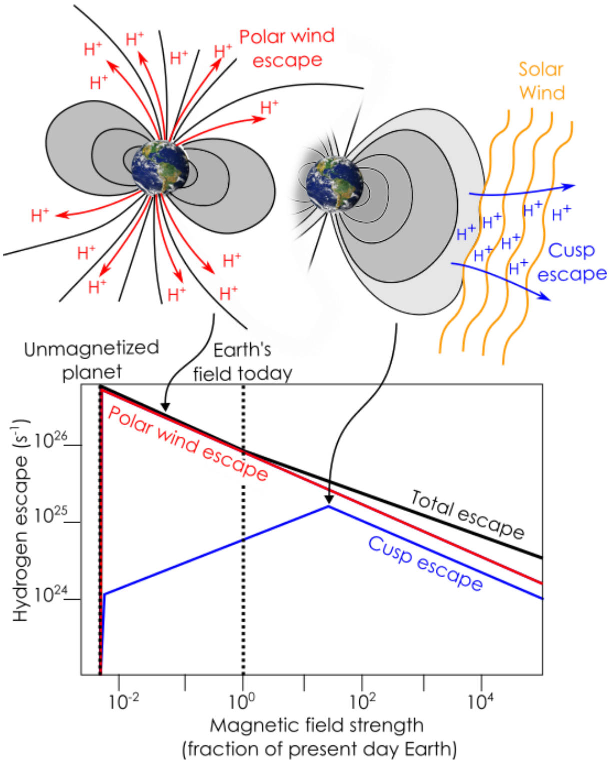

Figure showing how hydrogen escape from Earth's atmosphere is influenced by magnetic field strength. Adapted from Gunell et al., 2018.

Methodology

Geological mapping and field sampling (including drilling oriented cores) will be carried out during 1-2 field seasons in Canada. Samples will be measured using a 2G superconducting rock magnetometer to recover the strength and direction of the ancient magnetic field. Thin sections of each lithology will also be made for petrological analysis, and to image sources of magnetization using the quantum diamond microscope. Results will be used to carry out simple models of atmospheric escape, and make first-order estimates on the degree of hydrogen escape.

Timeline

Year 1: The student will begin by working on samples already collected from the Central Slave Cover Group, Northwest Territories, Canada. Paleomagnetic field tests will be carried out to identify primary paleomagnetic signals.

Years 2 and 3: Between years 1 and 2, focussed fieldwork will be carried out to target the most promising localities for primary paleomagnetic signals. The stability will be verified using the quantum diamond microscope to isolate stable sources. A small suite of samples will then be used for thermal demagnetization and paleointensity analysis. Results will be presented at the AGU fall meeting, and results of the paleomagnetic field tests written up for publication.

Year 4: Magnetic field strengths will be used to make inferences regarding the degree of potential hydrogen loss from the atmosphere prior to the GOE. Results will be presented at the AGU fall meeting and written up for publication.

Training & Skills

Throughout the project the student will have the opportunity to develop a variety of skills including:

- Geological mapping and sampling for paleomagnetic analysis
- Paleomagnetic analysis using a superconducting rock magnetometer, paleomagnetic furnaces and AF demagnetizer
- Petrographic analysis and electron microscopy
- Quantum diamond microscopy image acquisition and data analysis

- Python coding and programming skills
- Scientific reading, writing and presentation skills

References & Further Reading

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Further Information

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