Project title: The prevalence of eccentricity forcing on evolution and the carbon cycle

Supervisory Team
Rosalind Rickaby and Dmitry Filatov
Alba Gonzalez-Lanchas and Krisztina Sarkozi

Key Words
Milankovitch cycles, populations genetics, weathering geochemistry, phytoplankton

Overview
Detailed morphological records of coccolithophores over the last 2 million years coupled with whole genome analysis have, for the first time, revealed that there is a strong 400 kyr periodicity to the speciation and evolution of these calcifying algae\textsuperscript{1,2,7}.

There are hints from the geological record that a link between variations in the Earth orbit and speciation events may have been persistent through geological time and leave an imprint on the carbon cycle\textsuperscript{3,4,5,6}. This project aims to explore the extent to which evolution of photosynthetic organisms on land and in the ocean respond to orbital variations of the Earth around the sun and whether this provides a fundamental pacing to the carbon cycle.

Methodology
The observation that variations in the Earth orbit can affect evolution in calcifying plankton\textsuperscript{1} triggers a whole range of additional questions. Do all phytoplankton follow synchronous periodicity, as would be expected if it is driven by the same external factor, such as variations in Earth orbit? Do photosynthesisers on land follow the same pattern? Do the pulses in the extent of calcification and photosynthesis drive the carbon cycle in a systematic way? This project will bring together a novel blend of population genetics, with the marine fossil record and sedimentary geochemistry to explore the co-evolution of photosynthetic life and orbit.

This project aims to resolve to what extent variations in the Earth orbit affect population dynamics and evolutionary processes in major groups of photosynthesizing marine (diatoms, foraminifera) and terrestrial (e.g. boreal forest) organisms.

The project will benefit from a powerful combination of fossil- and DNA sequence-based analyses, as piloted in our recent work\textsuperscript{2,8}. Evolutionary genetic analyses of whole genome sequence data will be employed to reconstruct a record of past population size changes, which will be compared to species abundance in the fossil record. The phytoplankton species leave an enviable micropalaeontological fossil record, while pollen records provide information about the past of the major photosynthesisers on land. The project will validate genomic inferences of past population size changes against the population sizes in the sedimentary record of marine and terrestrial photosynthesizers over the last 2 million years.

New data suggest that the increase in calcite productivity during the Brunhes 400 kyr acme of coccolithophore productivity, may not be restricted to one species suggestive of some
extrinsic forcing on enhanced calcite production such as weathering inputs to the ocean. The project will therefore generate new geochemical proxy records on a 2 million year timescales that may be sensitive to weathering to explore whether a 400 kyr signal is also sensed in weathering inputs to the ocean (including but not restricted to $^{30}$Si, Si/particle, $^{10}$Be/$^{9}$Be).

Such an interdisciplinary combination of geochemistry, genomics and micropalaeontology will reveal novel mechanistic insight to the persistent Milankovitch periodicity in carbon cycle prevalent through Earth history.

**Timeline**

**Year 1:** Selection and request of samples of ocean sites for sample preparation and analysis

Training in sediment microseparation and microfossil identification and preliminary data collection

Training in DNA extraction, sequencing and preliminary bioinformatics/population genetics analysis

**Years 2 and 3:** Generation of population size reconstructions from genomes and the fossil record

Resolution of good age models for each record

**Year 4:** Synthesis of all data to explore whether orbit drives evolution of terrestrial biota, which drives weathering which drives evolution of phytoplankton or the orbital forcing is sense ubiquitously in photosynthetic organisms.

**Training & Skills**

Key skills and training in:

- Microfossil identification
- DNA extraction and whole genome analysis
- Geochemical weathering proxies, Earth System biosphere interactions

**References & Further Reading**

8. DA Filatov, EM Bendif, OA Archontikis, K Hagino, REM Rickaby. The mode of speciation during a recent radiation in open-ocean phytoplankton *Current Biology* **31**(24), 5439-5449. e5

**Further Information**

Contact: Prof Ros Rickaby (rosr@earth.ox.ac.uk)
Prof Dmitry Filatov (dmitry.filatov@biology.ox.ac.uk)