Exploring the epoch of rapid inner core growth

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Key words:	Earth's evolution; Inner core nucleation; Dynamics; Mineral physics
Research theme(s):	• Geophysics and Geodynamics • Planetary Evolution and Materials
Eligible courses for this project:	• MSc by Research in Earth Sciences (2-3 years) • DPhil in Earth Sciences (3-4 years) • Interdisciplinary Life and Environmental Science Landscape Award (ILESLA) • Intelligent Earth (UKRI CDT)

Overview

Our understanding of the long-term evolution of the Earth is informed by analysis of the history of the geomagnetic field that also protects the environment and permits surface habitability. This magnetic field is currently powered by the latent heat and light elements released by the growth of the solid inner core. However, deep in Earth's history there was no inner core and the geodynamo is believed to have been powered only by cooling of the then liquid iron core. Recently it has become clear that the initial period of growth of the inner core must have been extraordinarily rapid leading to dramatic changes in the dynamics of the whole core system that may be observable in the paleomagnetic record or in the seismic structure of the inner core (Huguet et al. 2018; Wilson et al. 2025; Figure 1). During this epoch of rapid growth our models of the thermal evolution of the Earth, which are routinely used in the initial epoch of gradual cooling and the current epoch of slow growth of the inner core, are invalid. In this project you will build on our initial work sketching out the consequence of rapid inner core growth and develop

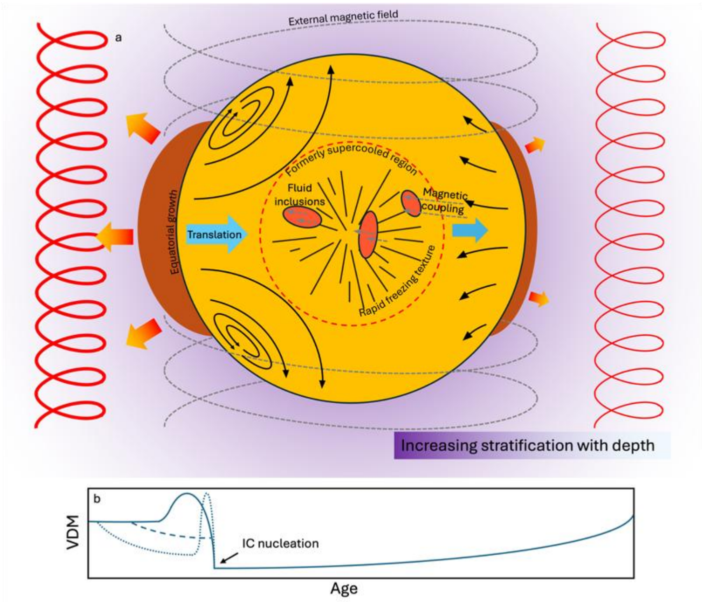

Figure 1 cartoon showing possible mechanisms leading to seismic structure of the inner core and the potential virtual dipole moment (VDM) of the magnetic field. From Wilson et al. (2025).

model that captures the important processes active during this time (Figure 2). You will integrate this model with existing tools that allow the prediction of the thermal evolution of the Earth and key parameters of the geodynamo. By comparing the resulting model with the paleomagnetic record you will begin to unravel the process by which the inner core formed.

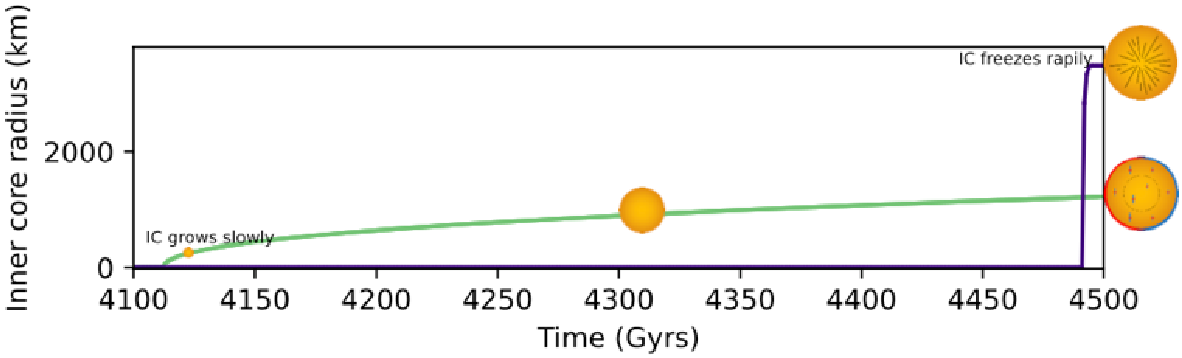

Figure 2 results of models of inner core growth with (purple) and without (green) delayed nucleation and a period of rapid growth. From Wilson et al. (2025)

The proposed project includes flexibility around the methodology used and research questions tackled as developing the detailed research plan is an integral part of doctoral level education. However, key aspects of the project will involve modelling the thermal evolution of the core and using the output of these models to predict the properties of Earth's magnetic field through time. These predictions will be compared with palaeomagnetic data from the rock record.

Methodology

The expectation of a period of initial rapid growth of the inner core comes from consideration of the energy barrier to freezing. Estimates for the Earth's core (e.g. Huguet et al. 2018; Davies et al. 2019, Wilson et al. 2023, 2025) imply that hundreds of degrees of undercooling are required. Once this barrier has been overcome, the inner core will start to grow quickly until equilibrium is reached and slow growth due to secular cooling commences. The first potential direction of research would involve studying the initial formation and growth of the inner core using atomic scale simulations, building on our work exploring the "nucleation paradox" (e.g. Davies et al. 2019, Wilson et al. 2023, 2025).

A second potential direction of research involves modifying existing models of the evolving energy budget of Earth's core (e.g. Greenwood et al. 2021) to account for the delayed nucleation event. The heat flux and entropy of these models provide ways to predict the nature of the geodynamo through geological time. The history of inner core growth rate provides information about the expected seismic structure of the inner core. You will use these predictions together with the observational record of the paleomagnetic record and/or information from seismology to test different scenarios of inner core formation.

The final and most challenging direction of research would involve direct numerical simulation of the magnetohydrodynamics of the outer core at times around the epoch of rapid inner core growth. Results of these simulations would permit improved links between the thermal evolution of the core and the nature of the geodyanmo at these times, and would strengthen our understanding of the link between the early rapid growth of the inner core and the paleomagnetic record.

Timeline

Year 1: Review of the inner core nucleation paradox and physics of the growth of the inner core, identification of key research questions and development of a research plan. Bespoke training in chosen methods.

Years 2 and 3: Modelling different scenarios for the evolution of the core examining the importance of delayed inner core nucleation. Comparison with the paleomagnetic record. Either atomic scale simulations of inner core nucleation or numerical simulation of the geodynamo with a small and rapidly growing inner core.

Year 4: Data integration, thesis completion, papers for international journals/conference presentation.

Training & Skills

You will become expert in linking processes occurring in the deepest interior of the Earth with observations that can be made at the surface. You are likely to develop skills in the development and use of numerical models of various types. These could include cutting edge methods in fluid mechanics, atomic scale simulation and/or machine learning. These methods will involve learning to use massively parallel supercomputers.

References & Further Reading

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Further Information

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