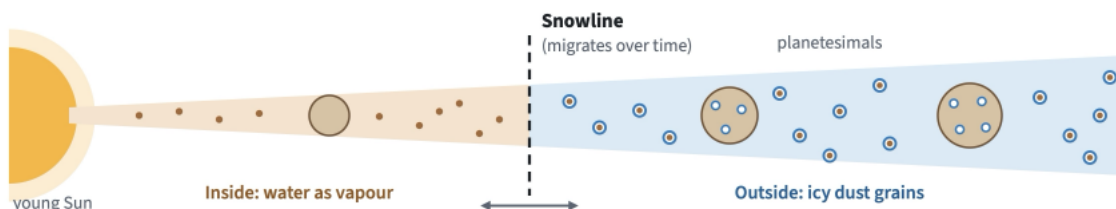


## Exploring the Drivers of Water-rock Interactions in Planetesimals as a Window into Snowline Behaviour

|                                           |                                                                                                                                                                                                                                                   |
|-------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
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| <b>Key words:</b>                         | Meteorites, planetesimals, water-rock interaction, snowline                                                                                                                                                                                       |
| <b>Research theme(s):</b>                 | <ul style="list-style-type: none"> <li>Planetary Evolution and Materials</li> </ul>                                                                                                                                                               |
| <b>Eligible courses for this project:</b> | <ul style="list-style-type: none"> <li>DPhil in Earth Sciences (3-4 years)</li> </ul>                                                                                                                                                             |

### Overview

#### a The snowline in the protoplanetary disk



#### b Rock and ice accrete



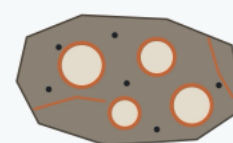
Planetesimals that form beyond the snowline incorporate water ice alongside rocky dust and chondrules.

#### c Ice melts; water reacts with rock



Heat from short-lived radioisotopes such as  $^{26}\text{Al}$  melts the ice, and the fluid reacts with the rock to form new minerals.

#### d A record preserved in chondrites



Fragments reach Earth as meteorites. Secondary minerals (orange) record how much water was present and the conditions of alteration.

Figure: schematic showing the protoplanetary disk, snowline, and formation of secondary phases during water-rock interactions.

One key feature within the protoplanetary disk of dust and gas that surrounded the young Sun was the snowline, i.e., the condensation front of water, interior to which water existed as a vapour in the gas and exterior to which water existed as solid ice. The snowline is crucial

because it corresponds to a fundamental change in the chemistry of accreting material, and its resulting changes in grain dynamics have been proposed to have facilitated planetesimal formation. As such, a detailed grasp on the location, evolution, and consequences of the snowline is central to elucidating planet building in the early solar system.

One way to investigate the snowline is through the mineralogy of meteorites, in particular unequilibrated chondrites that preserve evidence of water-rock interactions on their parent bodies. The phases present in these extraterrestrial rocks reflect the complex interplay between the amount of water (i.e., depends on formation environment of their parent body relative to the snowline) as well as the conditions on their parent body (e.g., peak temperature, duration of heating, pathway of water-rock interaction, redox state, etc.). By quantitatively analysing these phases in detail, it is possible to piece apart their rich histories to determine how much water was in the material that accreted to form these bodies. Combining this with model accretion ages of these bodies will unlock valuable insights into the evolution of the location of the snowline in the disk, providing a window into the role the snowline played in the formation of planetesimals.

The aim of this project specifically is to investigate the reasons why some chondrites appear to have experienced more extensive water-rock interaction (e.g., oxidised CV chondrites, some ungrouped chondrites) while others experienced less extensive reactions (e.g., reduced CV chondrites, CO chondrites, other ungrouped chondrites). One possibility is that their accretionary feedstocks contained different amounts of ice, i.e., they formed in different environments around/at the snowline, or different distances from the snowline, or as the snowline migrated; another possibility is that they contained similar amounts of ice, but the conditions on their parent bodies permitted differing extents of water-rock interaction. Distinguishing between these can be achieved by:

- Applying several micro-analytical measurement techniques (e.g., electron-probe microanalysis [EPMA], scanning electron microscopy [SEM]) to phases that formed during water-rock interaction (e.g., fayalite, magnetite, hedenbergite) to explore their chemistry, morphology, and abundance. These techniques will be applied to 1-3 thin sections across ~5-8 meteorites from 4-5 groups, with scope for modifications as the project evolves.
- Using thermodynamic computational models (e.g., Theriak-Domino) to explore which phases are expected to have formed under different conditions (e.g., amount of water, temperature, oxygen fugacity, etc.).

This combination will yield a more complete understanding of the formation processes and conditions of these phases, which will enable the amount of water in their pre-accretionary solids to be uncovered. As such, this approach provides a route to distinguishing between the scenarios outlined above, which is essential to uncovering the impact of the snowline on planetesimal formation.

In summary, this project aims to investigate a suite of chondrites to gain a granular picture of the impact of the snowline in the early solar system. The student will apply microanalytical techniques, data processing and interpretation, and thermodynamic modelling, gaining hands-on experience in each. The outcomes will be used to explore the extent to which the snowline influenced planetesimal formation and chemistry, providing a rich and detailed understanding of its role in early solar system evolution.

## **Methodology**

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- Electron probe microanalysis
- Thermodynamic modelling

- Electron microscopy
- Optical microscopy
- Potential for X-ray spectroscopy at synchrotrons

## Timeline

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**Year 1:** Training on equipment in various laboratories in the Dept of Earth Sciences; training on use and theory behind thermodynamic modelling; familiarisation with the background literature into water-rock interaction in chondrites; identification of best routes forwards; sample acquisition; initial data collection.

**Year 2:** Bulk of sample preparation, data collection and analysis; bulk of thermodynamic modelling; initial interpretation of new data alongside existing data.

**Year 3-4:** Complete data collection and analysis; integrate data alongside existing data and interpret complete dataset; write-up papers and thesis; present findings at national and international (e.g., LPSC, MetSoc) conferences.

## Training & Skills

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- Numerical data collection and analysis
- Scientific presenting
- Writing scientific papers
- Designing scientific projects
- Communication and project management skills
- Computational skills (e.g., Python)
- Option for teaching/mentoring

## References & Further Reading

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A. N. Krot et al., Metasomatic Alteration of Type 3 Ordinary and Carbonaceous Chondrites. *Space Science Reviews* (2025).

J. Drazkowska & Y Alibert, Planetesimal formation starts at the snowline. *Astronomy & Astrophysics* (2017).

A. N. Krot et al., Mineralogy, petrology, and oxygen-isotope compositions of magnetite±fayalite assemblages in CO3, CV3, and LL3 chondrites, *Meteoritics & Planetary Science* (2022).

Y. Marrocchi et al., Origin and abundance of water in carbonaceous asteroids. *Earth and Planetary Science Letters* (2018).

A. Morbidelli et al., Formation and evolution of a protoplanetary disk: Combining observations, simulations, and cosmochemical constraints. *Astronomy & Astrophysics* (2024).

## Further Information

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