In situ dating of meteoritic olivines

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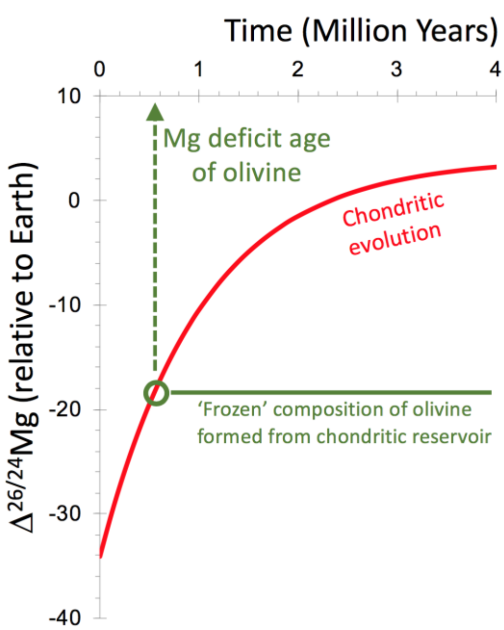

Fig 1: Evolution of solar system $^{26}Mg/^{24}Mg$, expressed in parts per million difference relative to modern Earth. When an olivine forms, it 'freezes in' the ambient Mg isotope composition. The Mg isotope composition of an olivine measured today can be used to obtain a model, Mg deficit age.

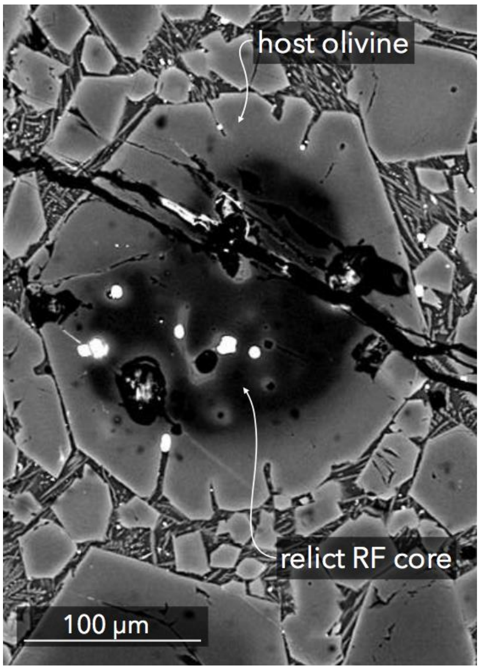

Fig 2: Back-scattered electron image of unequilibrated ordinary chondrite NWA 8276, showing an early formed, refractory forsterite (RF, dark shade) surrounded by more iron-rich olivine (lighter shade). Note bright, spinel inclusions.

Project Background

The timing and duration of solid formation in the earliest solar system is key for constraining dynamic models of the nebula and relating astronomical observation of young stellar objects to our own solar system (see Dauphas and Chaussidon, 2011; Connolly et al., 2012). High precision dating of objects >4.5Ga is challenging and the successful chronometers to hand only indirectly date solid formation. Unsurprisingly early solar system chronology is a subject of much debate (c.f. Bollard et al., 2017; Tenner et al., 2019).

One problem is that the main silicate minerals (e.g. olivine and pyroxene) which dominate most primitive bodies are not directly dated. Recent advances in analytical techniques, however, now make this possible. Due to the decay of short-lived ^{26}Al to ^{26}Mg (half-life ~750ka), the $^{26}Mg/^{24}Mg$ of the solar system evolves over the first ~3Ma of the solar system (Fig 1). Formation of Mg-rich phases such as olivine 'freeze in' the ambient Mg isotope ratio. The Mg isotope ratio of an ancient olivine measured today, provides a model 'Mg deficit' age of when its formation of olivine stopped further radiogenic additions to the $^{26}Mg/^{24}Mg$. Obtaining Mg-deficit ages requires very high precision measurements, as the total expected variation in $^{26}Mg/^{24}Mg$ is only ~35ppm. Modern mass-spectrometry makes such measurements possible, but this still represents a significant technical challenge. We have had some success in dating large (several 100μm), refractory olivine grains through painstaking preparation by laser milling (Gregory et al., in press). A more direct approach would be to use laser ablation of measurement of the ablated material. This has significant advantages in being able to monitor continuously possible incorporation of extraneous material (and reject such data if it occurs) and more efficiently sample grains. However, analysis by laser ablation introduces matrix components into the mass-spectrometer which complicates high precision measurements. This project will work to develop a high-precision, laser ablation approach and apply this to dating *in situ* a wide range of mafic minerals in primitive meteorites.

Project Aims and Methods

At Bristol, we have had significant success in making Mg isotope measurements to ±2ppm, on large samples purified by solution chemistry (Luu et al., 2019). This project will investigate the effects of matrix in trying to make Mg isotopic measurements to comparable precision by laser ablation. The project will use the well-equipped isotope laboratory at the University of Bristol, which has three multi-collector plasma mass-spectrometers (including a unique collision instrument that will be valuable to explore possible interferences) and two excimer laser ablation systems. The first part of the project will involve technique development, building on considerable experience within the lab. The second part of the project will apply the techniques dating components of meteorites. The exact targets will depend on progress in the lab. At worst, the project can continue to exploit the effective micro-sampling techniques already used by Gregory et al (in press) in exploring a wider range of primitive forsterite grains. More optimistically, approaches developed will allow Mg deficit dating of small grains, such as that pictured in Fig 2, and couple these with isochron ages, derived from *in situ* analysis of olivine and Al-rich, spinel inclusion (bright spots) using the same techniques. Such combined ages will allow the student to develop robust chronologies of major silicate formation in the solar system.

Candidate

The successful applicant should have a background in either Earth Sciences or a related physical science, preferably to MSc/MSci level. A strong interest in Earth or planetary sciences is essential, as too is an enthusiasm for practical, laboratory work and careful, analytical study.

Training

The project will be based around obtaining high-precision isotope data on meteorites and their constituent minerals. Therefore, we will provide training in laboratory techniques and mass spectrometry. The project requires the use of novel mass spectrometric techniques and supervisor Chris Coath has considerable experience in developing techniques to make cutting edge *in situ* analyses (e.g. McKeegan et al., 2011). Additional training will be given in microbeam techniques. The student will be expected to present results at national and international conferences and to publish findings in international journals. This will require excellent communication and written skills.

References / Reading List

Bollard, J., Connelly, J. N., Whitehouse, M. J., Pringle, E. A., Bonal, L., Jørgensen, J. K., Nordlund, Å., Moynier, F., and Bizzarro, M. (2017). Early formation of planetary building blocks inferred from Pb isotopic ages of chondrules. *Science Advances* **3**, e1700407.

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Eligibility:STFC PhD training grant funding is limited to UK resident students.

Application deadline: 23.59 BST, 1st May 2020

How to apply to the University of Bristol: http://www.bristol.ac.uk/study/postgraduate/apply/.

Please select PhD in Geology as the programme in the online application system.