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Mn, Co and Ni diffusion profiles in pallasite olivine

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Abstract

Using LA-ICP-MS, we have measured diffusion profiles for Co, and in some cases also been successful in obtaining Mn and Ni profiles, in olivine from the Brahin and Brenham pallasite meteorites and used them to constrain their relative cooling rates.

1. Introduction

Pallasites are mixtures of Fe-Ni metal and olivine interpreted to have originated at the core-mantle boundary of a differentiated asteroid [1]. To constrain the environment of pallasite formation, there has been considerable to determine the cooling rates of these rocks, either using metallographic microstructures [2] or elemental zoning in olivine [3].

With development of rapid and more precise techniques for in situ trace element analysis of olivine [4] such as Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS), and recent improvements in the understanding of trace element diffusion in olivine [5], a reassessment of pallasite olivine trace element distributions arising from diffusive modification and other processes is needed. As part of our broader study of pallasite olivine trace element [6] and Mn-Cr isotope [7] systematics, we have measured diffusion profiles for Mn, Co and Ni in two pallasites with contrasting petrographic textures: the Brahin pallasite (with fragmental olivine) and the Brenham pallasite (with rounded olivine).

2. Methods

LA-ICP-MS has been used to measure diffusion profiles in olivine grains with a method similar to that described by [4]. The laser beam was shaped with a rectangular slit, giving a sampling area 100 microns long and several microns wide. This was scanned at a rate of 1 micron per second across olivine and perpendicularly into the grain boundary (Figure 1).

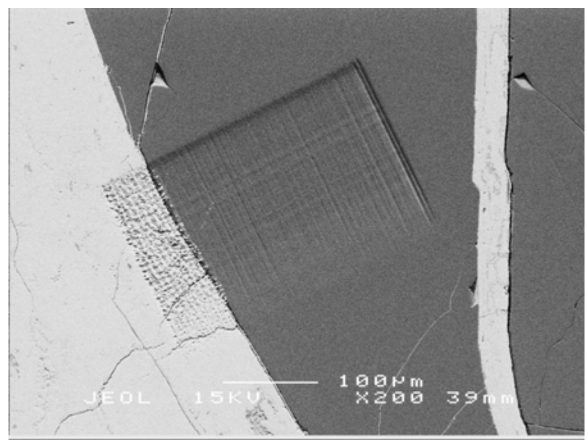

Figure 1: Back-scattered electron image of Brenham olivine (grey) and sulfide (white) after laser ablation for ICP-MS.

3. Results

We have obtained clear diffusion profiles for Co and in some cases for Mn and Ni as well (Figure 2). Ni concentrations in Brahin are steady or decrease very slightly at olivine margins, while in Brenham they do not change systematically from core to rim. Co decreases clearly within the outermost 10's or 100's of microns in olivine from both pallasites. The siderophile elements Ni and Co often show localized and correlated spikes in concentration, probably due to contamination by metal-filled cracks or micro-inclusions. Ni is affected by siderophile inclusions much more than Co and so it is more difficult to obtain a smooth profile for this element.

Mn is homogeneous throughout olivine in Brahin, with possible slight increases in the outermost 10 microns (this is close to the spatial resolution of our technique). Mn in Brenham olivine clearly increases in concentration in the outer few 10's of microns.

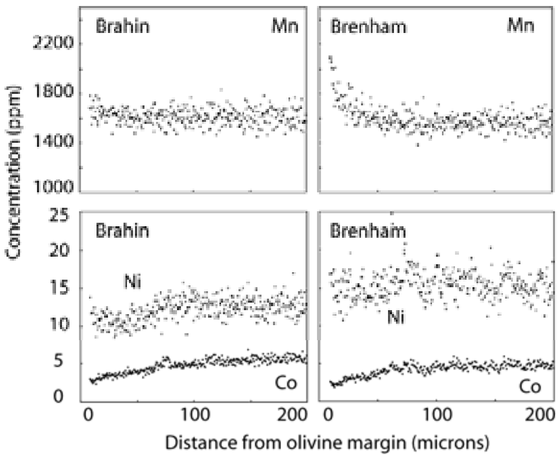

Figure 2: Selected Mn, Co and Ni diffusion profiles for Brahin and Brenham olivine.

4. Discussion

There is variation from scan to scan (e.g. Ni holding steady or decreasing in Brahin, while being steady or increasing in Brenham) which probably represents apparent changes in concentration due to sectioning not being perpendicular to olivine margins, or could reflect slight variations in diffusivity with crystal orientation [4]. An important effect highlighted by [3] is that Fe-Mg profiles in different olivine grains from the same pallasite sometimes change concentrations in opposite directions. This indicates that the local environment, such as the particular mineral assemblage surrounding each olivine grain, may have some control over diffusive modification.

That Mn has maintained homogeneity throughout olivine from Brahin and very nearly so in Brenham, while Ni and Co have not, indicates that the diffusivity of Mn is higher than Ni and Co under pallasitic conditions. This is consistent with work on natural terrestrial olivine [e.g. 8] which shows that Ni and Co diffuse at similar rates to Mn along the olivine c-axis but are slower along the b-axis.

The development of diffusion-in profiles for Mn in Brenham olivine over 10's of microns, while any similar effect in Brahin is much less developed, indicates that the cooling rate of Brenham was slower than Brahin and closure of Mn-diffusion occurred at lower temperature. This might seem qualitatively in agreement with the petrographic appearances of these meteorites, with Brahin having a brecciated texture while Brenham has rounded olivine. However, it has been shown that pallasite olivine morphology is unrelated to metallographic cooling rates [2], and that the required timescale for complete rounding of a coarse, fragmental olivine protolith is, at subsolidus conditions, too long to be relevant for pallasite petrogenesis [9]. The most recent data shows that pallasites cooled below 975 K at 2.5-18 K/Myr [2]. This span in cooling rates of less than a factor of 10 is consistent with the scales of Mn diffusion profiles observed in Brahin and Brenham, at ~10 microns (near detection limit) and 10's of microns respectively. With a metallographic cooling rate for Brenham at 6.2 +/- 0.9 K/Myr [2], the subsolidus cooling rate of Brahin is likely near the upper end of the pallasite range (~18 K/Myr).

6. Summary and Conclusions

Using LA-ICP-MS, we have obtained diffusion profiles for Co and in some cases also for Mn and Ni in olivine grains from the Brahin and Brenham pallasites. The relative lengths of diffusion profiles are consistent with current understanding of the relative diffusivities of these elements in olivine, and allow inference on the cooling rate of the Brahin pallasite.

Acknowledgements

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References

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