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LETTERS

Survival times of anomalous melt inclusions from element diffusion in olivine and chromite

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Basaltic magma

end product of a complex series of processes

High pressure

Partial melting

↓

Melt extraction from a mantle source

↓

Fractional crystallization

↓

Crustal assimilation at lower pressure

Low pressure

Basaltic magma

end product of a complex series of processes

Primary information at early crystallization stage
is hidden by the complex processes

To know the primary information…

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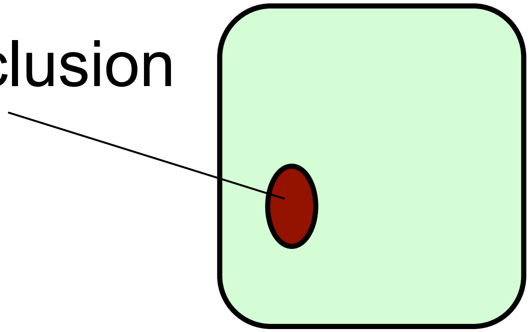
Melt inclusions

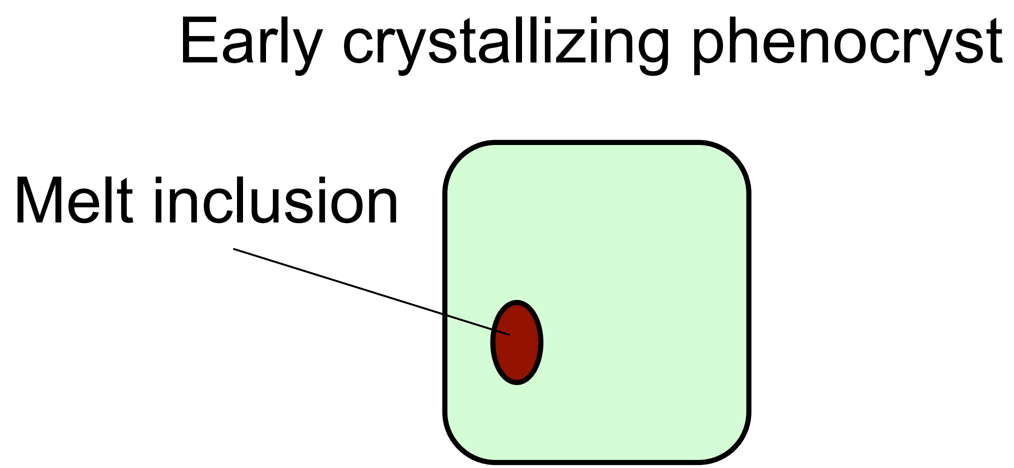
Melt inclusions trapped in early crystallizing phenocryst could help to see back to the origin of the partial melt in the mantle beyond the later-stage processes.



Melt inclusions

People so far discussed the mantle heterogeneities/melt genesis based on the distinct chemical composition (i.e. incompatible elements such as REE) of the melt inclusions

(Schiano, 2003; Sobolev, 1996; Sobolev et al., 2000; Ren et al., 2005)



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Melt inclusions

important assumption

Melt inclusions, once trapped, remain chemically isolated from the external magma for all elements

↓

Negligible flux of the trace elements through the host crystal (I.e., olivine, chromite) by lattice diffusion

Partitioning coefficients and diffusion coefficients of incompatible elements (like REEs) in olivine and chromite are so low that isolation is effective.

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Melt inclusions

There are no data on diffusion coefficients and this important assumption has never been tested..

In this paper..

To evaluate this assumption,

Multi-component chemical difusion experiments have been conducted on olivine and chromite crystals

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Experimental method

Starting materials

Olivine (Fo89-90) containing melt inclusions
Dredged from southern Mid-Atlantic Ridge
1-2 mm in size

Chromite from the Stillwater Complex

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Olivine

before experiments

Melt inclusions share similar compositions to the typical primitive high-Mg MORB liquids

Trapping temperature (1230-1280 degree C) were recorded to homogenize the melt inclusions

A glass of basaltic composition was prepared with ~400 ppm of the REEs, Pr, Eu, Tb, Ho and Lu to simulate the external melt

Olivine

experimental

Olivine crystals + powdered glass (in Re buckets)

↓

Gas-mixing (CO/CO2) furnace at 1300 degree C
for 1, 5 and 25 days, and quenched rapidly

↓

Analyze the chemical composition and diffusion profiles
Of polished olivine crystals by ICP-MS

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1 day experiments

a

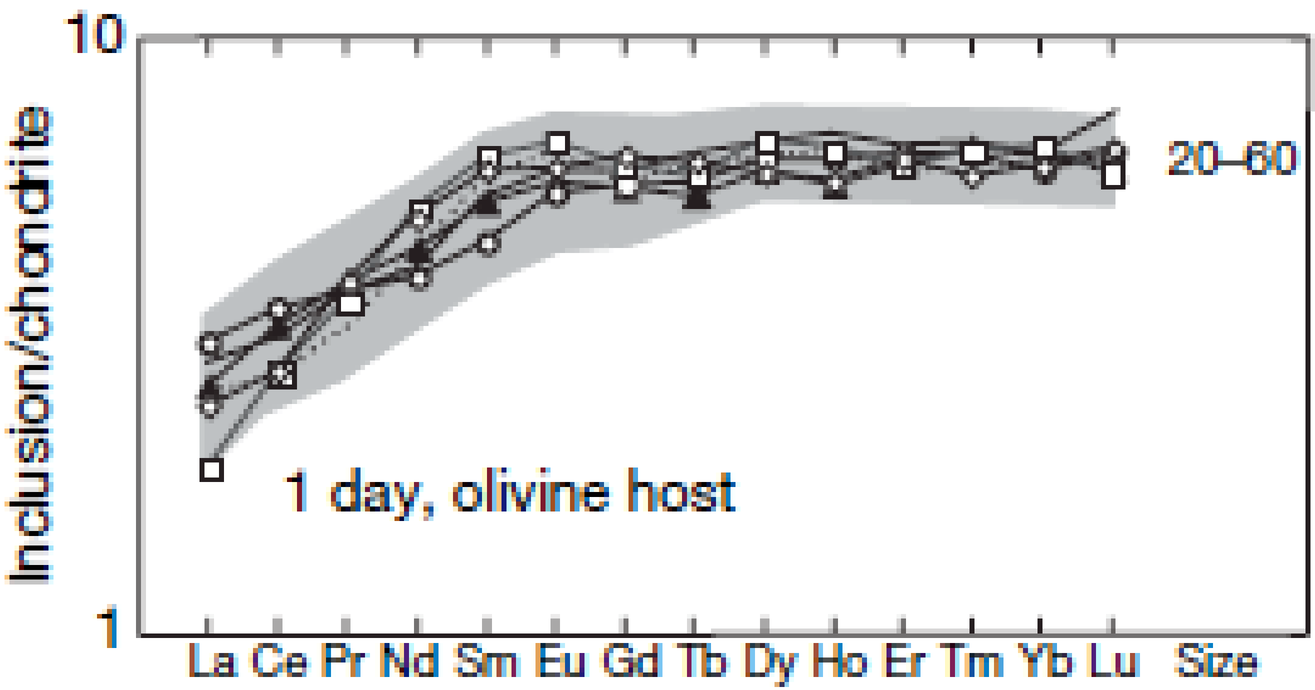
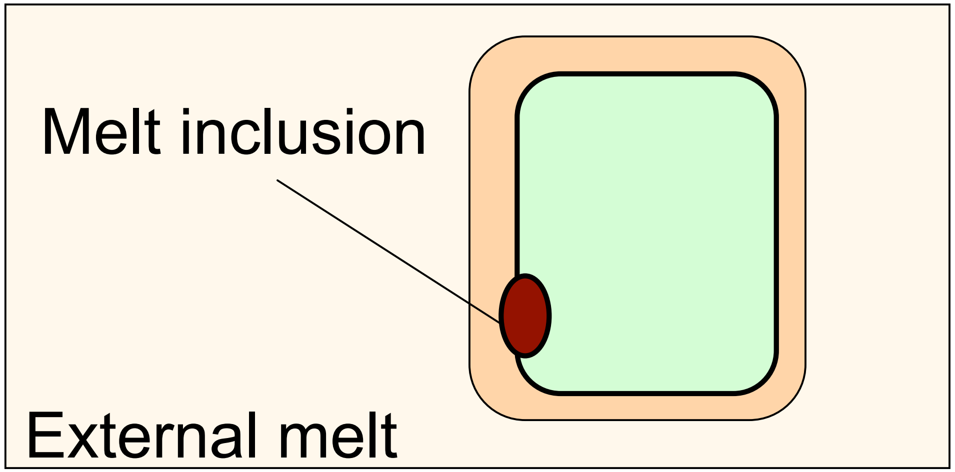


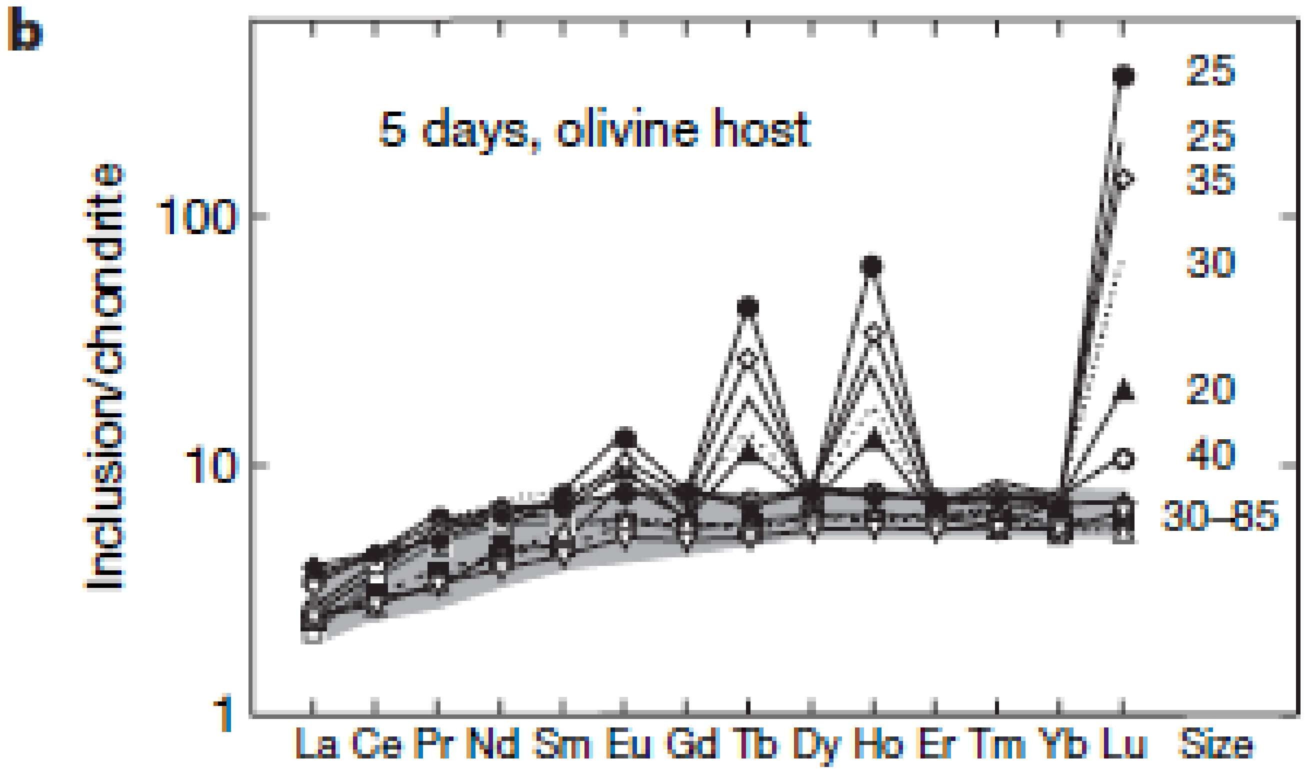
Figure 1 | Chondrite-normalized REE plots of olivine- and chromite-hosted melt inclusions. The grey fields represent the compositional range of normal melt inclusions after homogenization. **a–c**, Representative olivine-hosted melt inclusions from the 1-day (**a**), 5-day (**b**) and 25-day (**c**) experiments. **d**, Chromite-hosted melt inclusions from a 7-day experiment. Inclusion size is in μm.

1 day experiments for olivine

Section of olivine up to 50 micron from the olivine/external melt interface have elavated Lu, Ho and Tb contents



5 days experiments



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Enriched in Lu, Ho, Tb and Eu

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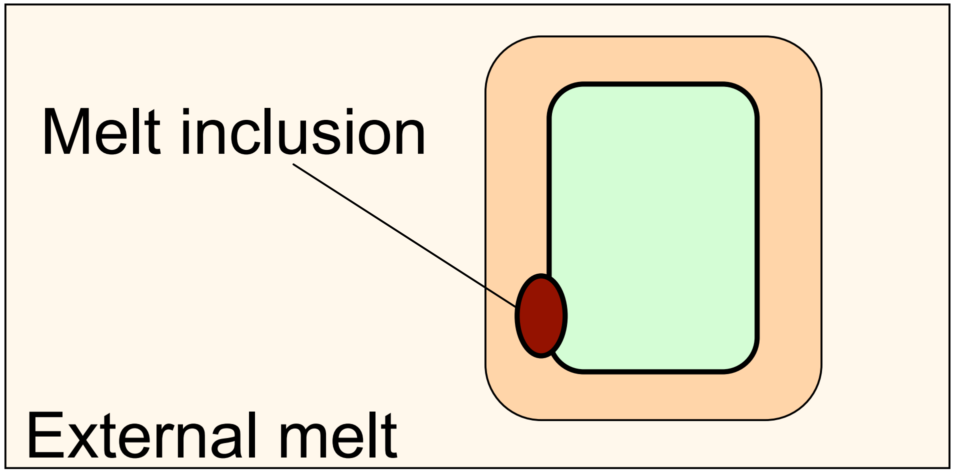
5 day experiments for olivine

Section of olivine up to 100 micron from the olivine/external melt interface have elavated Lu, Ho and Tb contents



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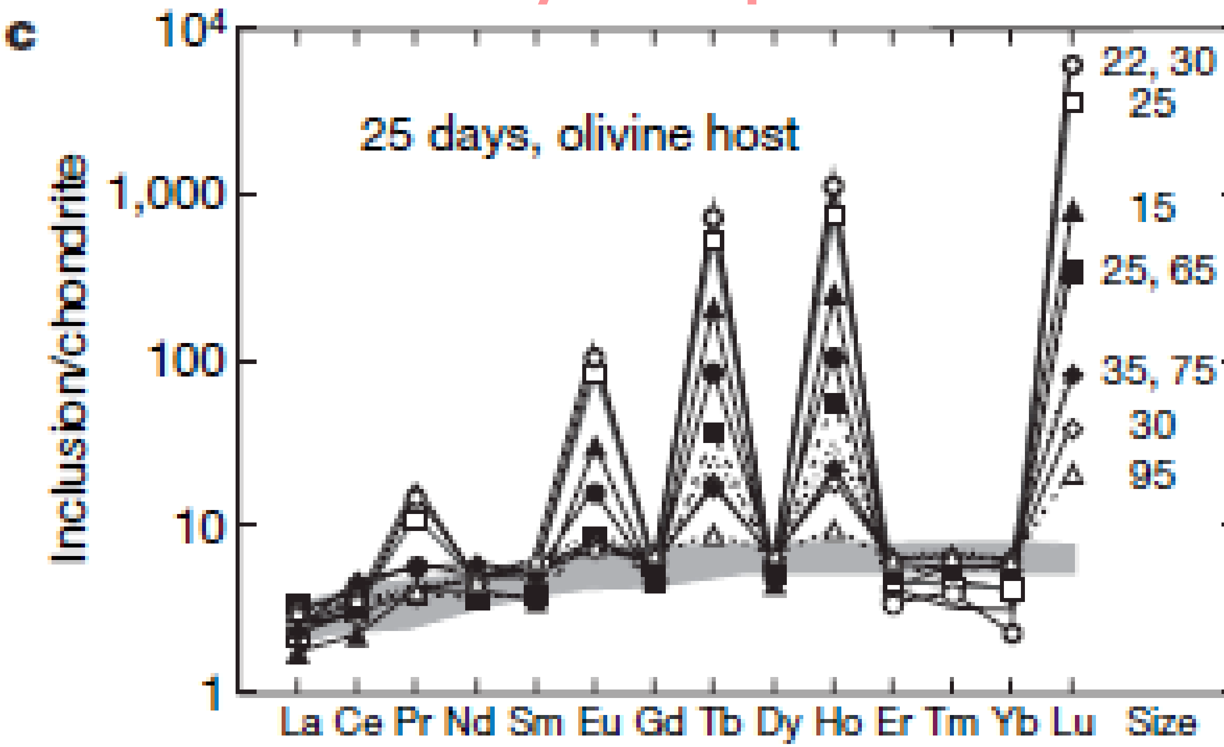
25 days experiments



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Enriched in Lu, Ho, Tb and Eu

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25 days experiments

Inclusions with the most extreme REE patterns tend to be small, located within 50 microns of an olivine grain boundary

Enriched in Lu, Ho, Tb and Eu
Depleted in heavy REEs (Er, Tm, Yb)

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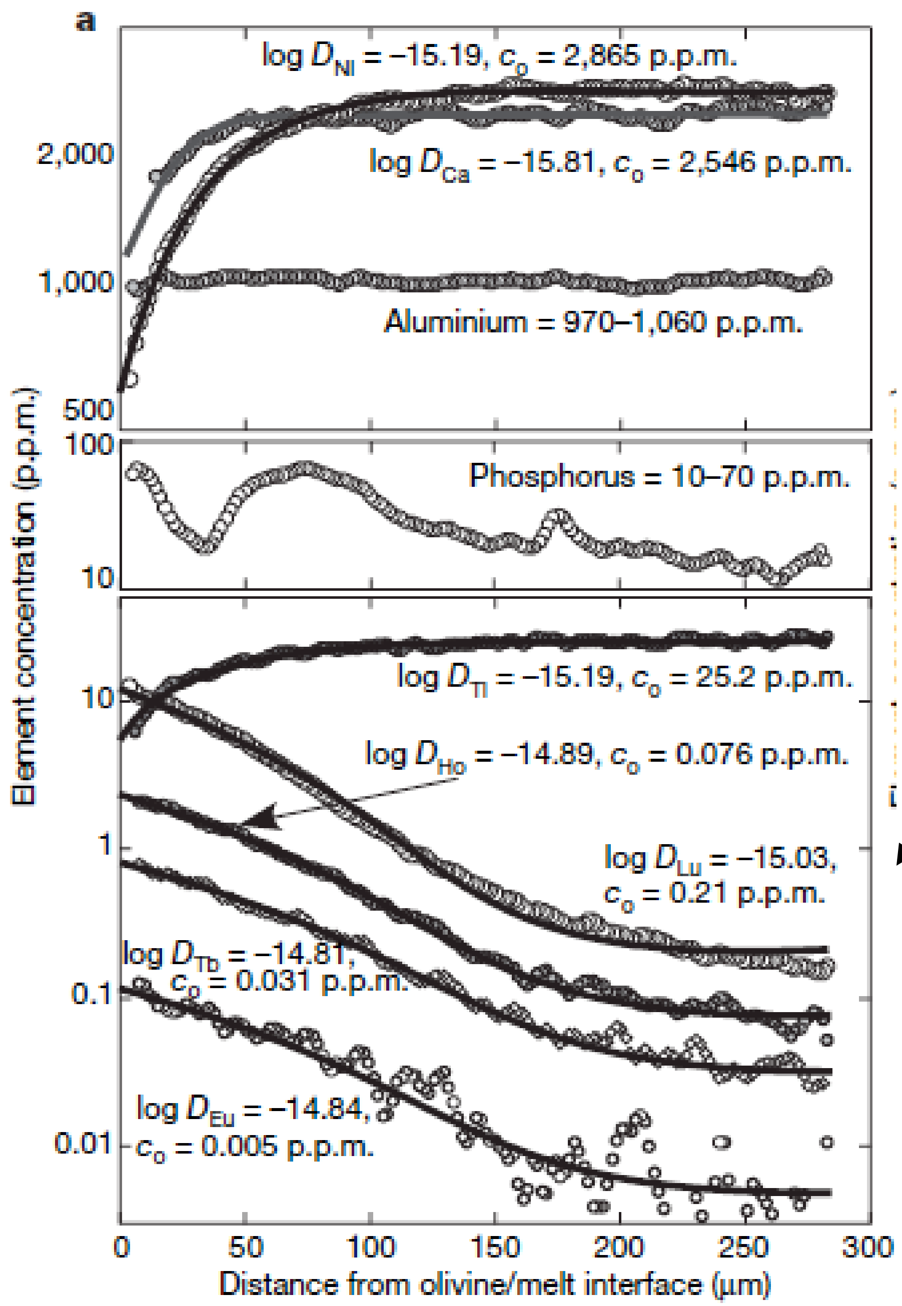

Diffusion profiles from analtical traverses

Elevated levels of REEs were decreasing from melt/olivine interface towards the interior of the olivine along the diffusion profiles

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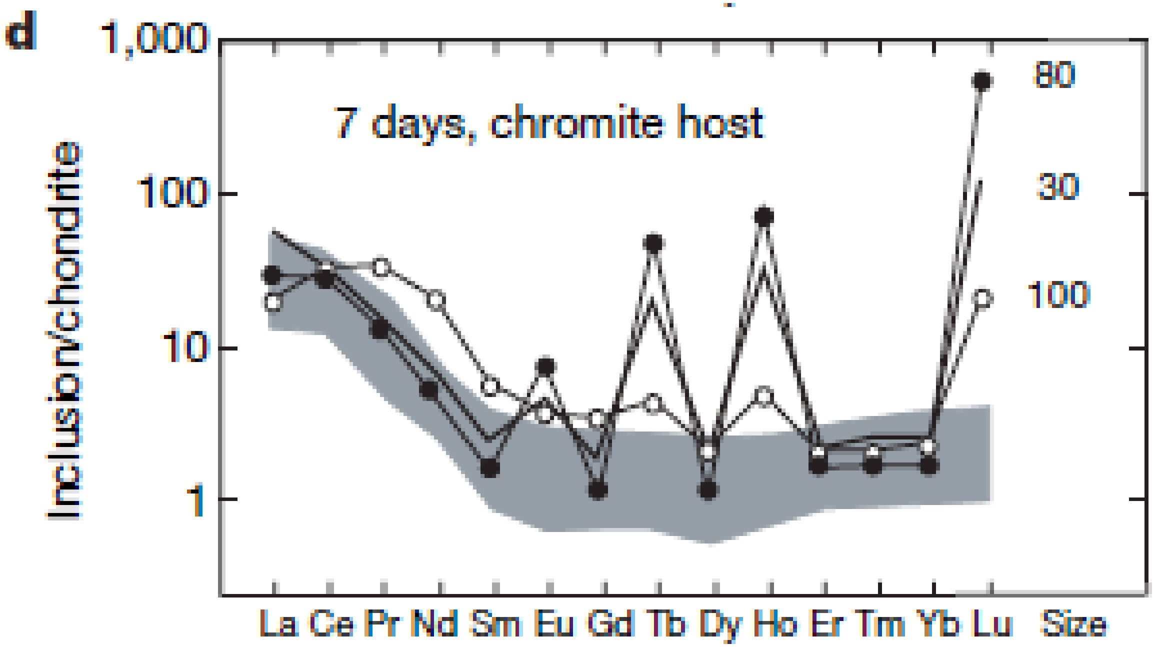
7 days experiments for Chromite



Similar results were obtained

The enrichment of REEs is attributed to diffusion of these elements from the external melt through the olivine and chromite

Substitution mechanism of REEs may be;

$$4/3REE^{3+} + M_2SiO_4 = 2M^{2+} + (REE_{2/3}vac_{1/3})_2SiO_4$$

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REEs diffusion is sufficiently rapid to re-equilibrate REE patterns of trapped melt inclusions

Time scale of the processes for production of basaltic magma

- Partial melting
- Melt extraction from a mantle source
- Fractional crystallization
- Crustal assimilation at lower pressure

10 to 10^5 years

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50 microns melt inclusions trapped within 1 mm olivine

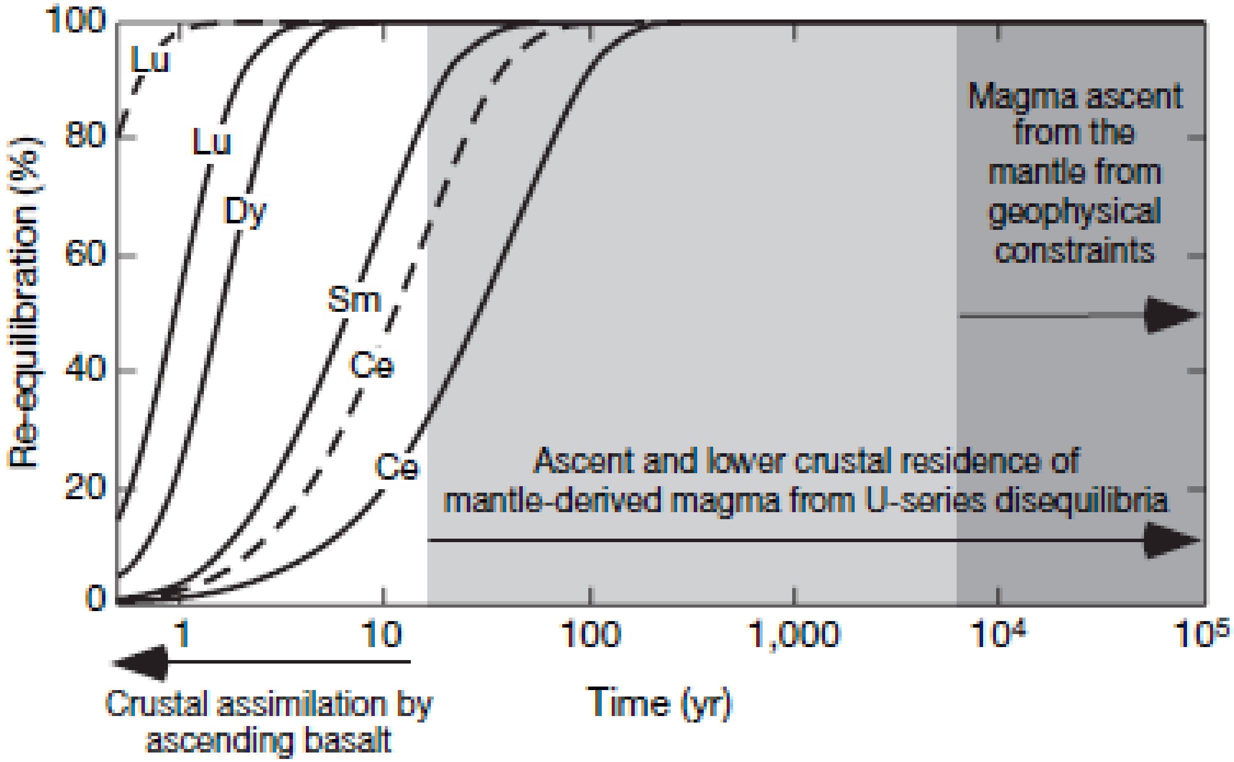

Figure 3 | Modelled re-equilibration times for REEs between a melt inclusion in an olivine grain and an external melt at 1,300 °C. Solid curves, a 50-μm

Anomalous signatures of REEs in melt inclusions can form shortly before magma eruption and cooling at shallower stage

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Conclusion

Isolation of inclusions in olivine/chromite may not be sufficient to preserve the primary information against many modification of melt extraction processes