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The primordial He budget of the Earth set by percolative core formation in planetesimals

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Supplementary Information

The Supplementary Information includes:

- Noble Gas Mass Spectrometry
- High-pressure Experiments
- Mass Balance Calculations
- Supplementary Information References

Noble Gas Mass Spectrometry

Gases were completely extracted in one step by melting with an Nd:YAG infrared laser and He and Ne were measured using an in-house built high-sensitivity magnetic sector field mass spectrometer equipped with a compressor source (Baur, 1999) following the procedure given by Riebe *et al.* (2017). The ionizing electron energy was 40 eV and the monitored contributions of $^{40}Ar^{++}$ on mass 20 amu (^{20}Ne) and of CO_2^{++} on mass 22 amu (^{22}Ne) were negligible. Sample gas amounts were not corrected for blank contributions because the blank values scattered around zero. Spectrometer sensitivities were determined using accurately known calibration gas aliquots of a He and Ne mixture, which were expanded into the same volume as used for the sample gases. The mixture had the following isotopic compositions: $^{3}He/^{4}He = 3.63 \times 10^{-6}$, $^{20}Ne/^{22}Ne = 9.70$, and $^{21}Ne/^{22}Ne = 2.89 \times 10^{-2}$. The difference in gas amounts between samples and standards was up to four orders of magnitude. We did not observe any pressure-driven effects; the miniaturised Baur-Signer source of the mass spectrometer was specially designed to minimise the dependency of the instrument's sensitivity on the pressure.

High-pressure Experiments

Starting materials were loaded into graphite capsules. The graphite capsules were fitted into platinum capsules that were sealed by arc welding. Gas loss during welding could not be excluded. The experiments were performed in an end-loaded piston cylinder press with a 14 mm bore. Piston cylinder assemblies consisted of external Talc-Pyrex sleeves, a graphite furnace, and inner crushable MgO cylinders containing the capsule and a mullite thermocouple ceramics. B-type Pt–Rh thermocouples were used to control the temperature. The thermocouple was separated from the Pt-capsule by a corundum disk. Run pressure was calibrated against fayalite + quartz = orthoferrosilite (Bohlen *et al.*, 1980) and the quartz–coesite transition (Bose and Ganguly, 1995). Experiments were quenched at a cooling rate of about 50 °C/s down to <300 °C.

Mass Balance Calculations

For closed system equilibration, simple mass balance between metal and silicate yields:

$$FC_s + (1-F)C_m = C_{bulk} \quad \text{(Eq. S-1)}$$

and since

$$D = \frac{C_m}{C_s} \quad \text{(Eq. S-2)}$$

then

$$F\frac{C_m}{D} + (1-F)C_m = C_{bulk} \quad \text{(Eq. S-3)}$$

and

$$FC_s + (1-F)DC_s = C_{bulk} \quad \text{(Eq. S-4)}$$

where F is the mass fraction of silicate, C_s is the He concentration in the silicate, C_m is the He concentration in the metal, C_{bulk} is the He concentration in bulk Earth, and D is the partition coefficient of He between metal and silicate. Solving Equations S-3 and S-4 for the ratios C_m/C_{bulk} and C_s/C_{bulk}, respectively, yields:

$$\frac{C_m}{C_{bulk}} = D(F(1-D)+D)^{-1} \quad \text{(Eq. S-5)}$$

and

$$\frac{C_s}{C_{bulk}} = (F(1-D)+D)^{-1} \quad \text{(Eq. S-6)}$$

Equations S-5 and S-6 can be used to calculate the He concentration in metal and silicate during percolative core formation in planetesimals (liquid-solid partitioning) and in a magma ocean (liquid-liquid partitioning) assuming D is constant for all F.

A second set of mass balance equations describes the He concentrations in the Earth's early core (C_{core}) and the Earth's early mantle (C_{mantle}) as a function of the fraction of precursor core equilibration (F_{eq}) during Earth's accretion:

$$C_{core} = F_{eq}C_m^* + (1-F_{eq})C_m^\# \quad \text{(Eq. S-7)}$$

$$C_{mantle} = F_{eq}C_s^* + (1-F_{eq})C_s^\# \quad \text{(Eq. S-8)}$$

where the superscripts [*] and [#] denote the He concentrations in a magma ocean (liquid-liquid partitioning) and in planetesimals (liquid-solid partitioning), respectively.

Supplementary Information References

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