

**TRACE ELEMENT CHEMISTRY DURING METAMORPHISM ON ORDINARY CHONDRITE PARENT BODIES.** Laura Schaefer and Bruce Fegley, Jr., Planetary Chemistry Laboratory, Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130-4899. Email: [laura\\_s@wustl.edu](mailto:laura_s@wustl.edu), [bfegley@wustl.edu](mailto:bfegley@wustl.edu).

**Introduction:** Trace element chemistry during ordinary chondrite metamorphism is a long-standing question [1]. We address this issue using thermochemical equilibrium calculations for major and trace elements during metamorphism of ordinary chondritic material. Trace element volatility sequences are important for trace element distribution inside asteroids with ordinary chondrite compositions. Our results below give the first volatility sequences for trace elements in H-, L-, and LL-chondritic material. These are slightly different than the volatility sequence during condensation in the solar nebula [2]. We also find that trace element abundances as a function of petrographic types 4-6 in equilibrated ordinary chondrites do not correlate with the calculated volatility sequences. This conclusion agrees with that of [3-4].

**Methods:** We did thermochemical equilibrium calculations for average H-, L-, and LL-chondritic material as a function of temperature (300 – 1600 K) and pressure (0.1 – 100 bars). Methods, bulk compositions, and results for the major elements are given in [5]. Trace element (Ag, As, Au, Bi, Br, Cd, Cs, Cu, Ga, Ge, I, In, Pb, Rb, Sb, Se, Sn, Te, Tl, Zn) abundances were taken from a number of sources (see [6] for complete details and results). Median abundances for the trace elements were used. Where these differed significantly from mean abundances, the effect of variable abundances on the results was calculated

**Results:** Figure 1 shows stability curves as a function of pressure for trace elements in average H-chondritic material. The dotted line is the nominal temperature-pressure profile of the supposed H-chondrite parent body (asteroid 6 Hebe) [7]. Results are discussed below by periodic table groups. Differences in chemistry for average L- and LL-chondritic material are noted where applicable. The volatility sequences are in order of increasing volatility, i.e. from the most refractory to most volatile phases.

**Group IA: Rb, Cs.** In H-chondritic material (Fig. 1B), the volatility sequence is RbCl (s,l) < RbBr (s,l) < CsI (s,l). In L-chondritic material, RbI (s) forms at higher temperatures than CsI (s,l). In LL-chondritic material, the volatility sequence is RbCl (s,l) < RbBr (s,l) < CsBr (s) ~ CsI (s,l).

**Group IB: Cu, Ag, Au.** In H-chondritic material (Fig. 1A), the volatility sequence is Cu<sub>2</sub>S (s,l) < Au (s,l) < Ag (s,l) < Cu (s,l). Cu<sub>2</sub>S (s,l) forms at temperatures greater than our highest temperature calculation

(1600 K). In LL-chondritic material, and at high pressures in L-chondritic material, Au and Ag volatility reverses. However, their stability curves remain similar to those of H-chondritic material.

**Group IIB: Zn, Cd.** (Fig. 1D) Zinc is primarily ZnSiO<sub>3</sub> ideal solid solution in enstatite, with minor amounts of Zn<sub>2</sub>SiO<sub>4</sub> in olivine. ZnSe (s) forms as a minor phase (<20% of total Zn) at ~820 K, independent of pressure, and decomposes at 370 K to form FeSe<sub>0.961</sub> (s). ZnCr<sub>2</sub>O<sub>4</sub> (s) forms at 650 K, independent of pressure. The initial cadmium phase is CdSe (s) at pressures > 1 bar and is CdTe (s) below 1 bar. CdSe (s) converts into CdTe (s) at ~730 K independent of pressure. CdTe (s) is present until ~470 K, below which all cadmium is reconverted into CdSe (s). Results are similar for H-, L-, and LL-chondritic materials. We did not include Hg in our calculations because its abundance in ordinary chondrites is very uncertain.

**Group IIIA: Ga, In, Tl.** In H-chondritic material (Fig. 1B), the volatility sequence is Ga<sub>2</sub>O<sub>3</sub> (s) < InS (s) < TlI (s) at pressures < 10 bar. At higher pressures, TlI (s) forms at higher temperatures than InS (s). In L- and LL-chondritic material the formation temperatures of InS (s) are higher than in H-chondritic material, so at all pressures InS (s) < TlI (s).

**Group IVA: Ge, Sn, Pb** In H-chondritic material (Fig. 1C), the volatility sequence at pressures < 5 bars is PbSe (s) < Ge (s) < Sn (l) < SnS (s) < GeO<sub>2</sub> (s). At higher pressures, Ge (s) forms at higher temperatures than PbSe (s). In L-chondritic material, Sn (l) forms at higher temperatures than PbSe (s) at pressures > 1 bar. In LL-chondritic material, the volatility sequence is the same as in H-chondritic material, but formation temperatures for PbSe (s), Ge (s), and Sn (l) are lower and those for SnS (s) and GeO<sub>2</sub> (s) are higher.

**Group VA: As, Sb, Bi.** In H-chondritic material (Fig. 1A), the volatility sequence is Sb (s) < Bi (s,l) < As (s). Formation temperatures in L- and LL-chondritic material are nearly identical.

**Group VIA: Se, Te.** In H-chondritic material (Fig. 1C-D), the initial Se phase is PbSe (s), followed by ZnSe (s) at pressures < 10 bars, and CdSe (s) at higher pressures. ZnSe (s) converts into FeSe<sub>0.961</sub> (s) at ~370 K, and CdSe (s) is present below 470 K. In L- and LL-chondritic material, the stability curve of PbSe is slightly lower than that of ZnSe (s) at low pressures, but is otherwise similar. Tellurium initially forms FeTe<sub>0.9</sub> (s). CdTe (s) is present from 470 – 730 K, but

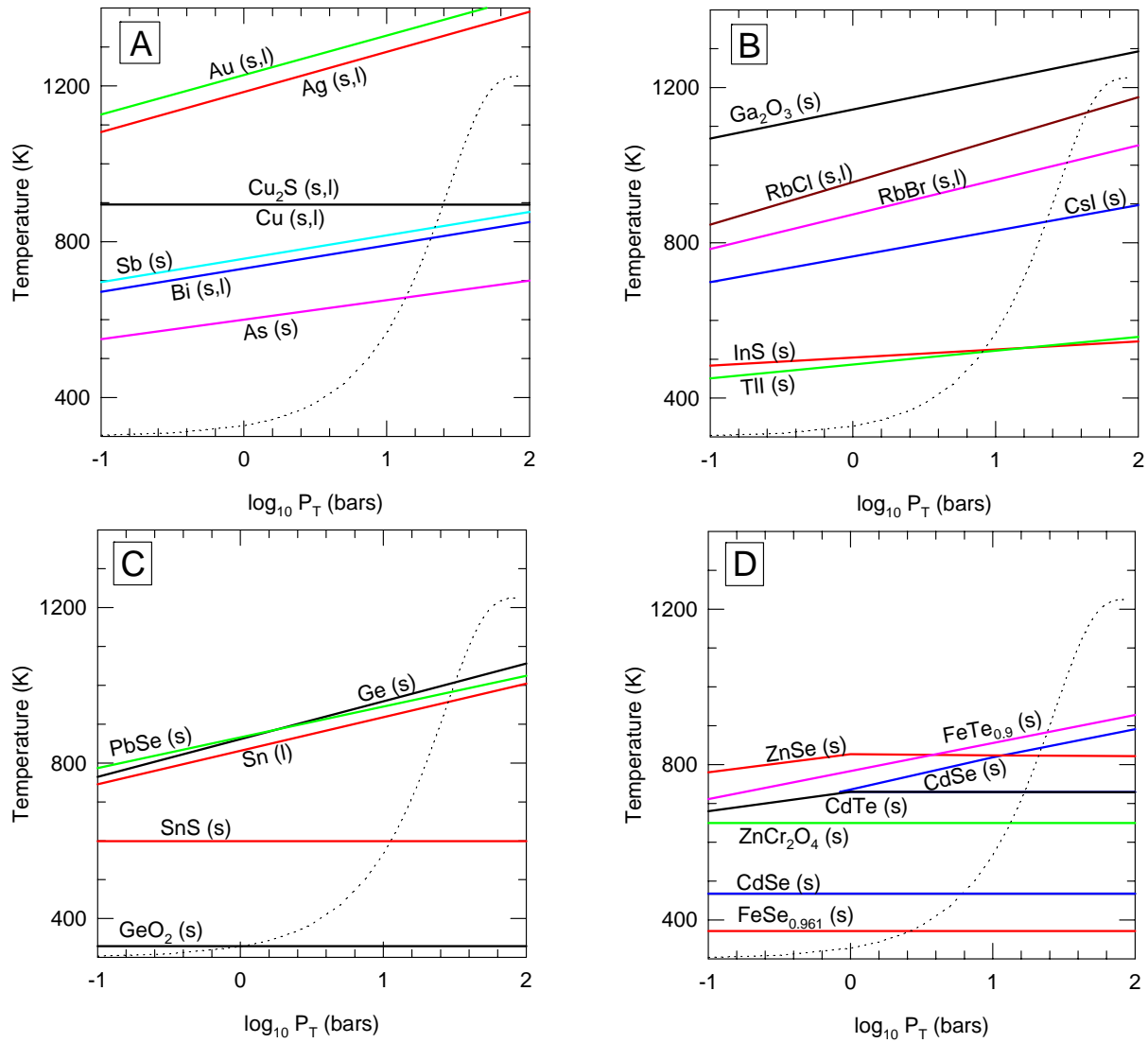
is destroyed at lower temperatures by CdSe (s). Results for L- and LL-chondritic material are similar.

**Discussion:** The overall volatility sequences at 1 bar pressure are, in increasing order of volatility: Cu, Au, Ag, Ga, Rb, Pb, Se, Ge, Zn, Sn, Te, Cs, Sb, Cd, Bi, As, In, Tl (H-chondritic material); Cu, Au, Ag, Ga, Rb, Ge, Pb, Se, Zn, Sn, Cd, Te, Sb, Bi, Cs, As, In, Tl (L-chondritic material); Cu, Au, Ag, Ga, Rb, Pb, Se, Ge, Zn, Cd, Sn, Cs, Te, Sb, Bi, As, In, Tl (LL-chondritic material). Cadmium is more volatile in H-chondritic material than in L- or LL-chondritic material, while Cs is more volatile in L-chondritic material. We found that the calculated volatility sequence does not correlate significantly with elemental abundances as a function of petrographic type in equilibrated ordinary chondrites. This agrees with the findings of [3]

and [4], who found no systematic trend (e.g.,  $6 > 5 > 4$ ) for trace element abundances in H chondrites or mildly-shocked L chondrites.

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**Figure 1.** Trace element stability curves in average H-chondritic material. The dotted line represents the temperature pressure profile for the asteroid 6 Hebe (possible H-chondrite parent body) shortly after accretion. A – Au, Ag, Cu, Sb, Bi, As. B – Ga, Rb, Cs, In, Tl. C – Pb, Ge, Sn. D – Zn, Cd, Se, Te.