

Experimental constrains on shock conditions of meteorites based on non-equilibrium behaviors of silica and plagioclase

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Recent studies on shocked meteorites have revealed non-equilibrium behaviors of silica and plagioclase at high pressures. We focus on the following three points observed in meteorites to deduce the P-T-t shock conditions from high-pressure kinetic experiments. 1) The formation of seifertite as a high-pressure polymorph of silica, 2) The occurrence of jadeite from plagioclase that does not contain stishovite, 3) The formation of lingunite as a high-pressure polymorph of albite-rich plagioclase.

Seifertite is a polymorph of silica with alpha-PbO₂ type structure that was found in shocked Martian and lunar meteorites (e.g., Sharp et al., Science1999; Miyahara et al., PNAS2013). Although this phase is thermodynamically stable at more than 90 GPa corresponding to the base of the lower mantle (Murakami et al., GRL2003), it has also been known that it metastably appears from cristobalite at around more than 40 GPa and room temperature (Dubrovinsky et al., CPL2001). We have carried out high-pressure and high-temperature in-situ XRD experiments of cristobalite using a Kawai-type multi-anvil (KMA) apparatus, and determined the formation kinetics of metastable seifertite and the following stable phase of stishovite. Because the activation energy for the seifertite formation is very low (~10 kJ/mol), which is consistent with the recently proposed formation mechanism (Blab, PCM2013), it can metastably appear at low T conditions beyond the negative PT boundary from ~10 GPa and 400C to ~30 GPa and room T. We found the clear difference in the formation kinetics between seifertite and stishovite, which enables to estimate the P-T-t shock conditions from the coexistence of these phases in various ratios in meteorites.

The occurrence of jadeite from plagioclase that does not contain stishovite has been often reported in shocked meteorites (e.g., Kimura et al., MAPS2000). In-situ XRD study using KMA apparatus have revealed that jadeite forms first from (amorphous) plagioclase, whereas the nucleation of other minerals such as stishovite or garnet is significantly delayed (Kubo et al., NGEO2010). The missing stishovite problem can be explained owing to the differences in crystallization kinetics of high-pressure phases from plagioclase. The hybrid shock indicator combining these non-equilibrium behaviors of silica and plagioclase mentioned above consistently and strongly constrains the P-T-t shock conditions of Martian meteorites.

The formation of lingunite (albite-rich hollandite) in shocked meteorites (e.g., Gillet et al., Science2000; Tomioka et al., GRL2000) has remained unsolved. This phase appears in laser-heated diamond anvil cell (LHDAC) experiments as a minor phase at around ~20-24 GPa and ~1000C (Liu, PEPI1978) and ~2000C (Tutti, PEPI07). However, KMA experiments indicate that the maximum solubility of NaAlSi₃O₈ component in hollandite structure is limited to ~50 mol% (Yagi et al., 1994, Liu, 2006). This clear contradiction may be due to the non-equilibrium origin. It has been suggested that the rapid T quenching in LHDAC experiments is important for the survival of lingunite metastably to the ambient condition. Our previous in-situ XRD study using KMA apparatus have indicated that lingunite is not formed at least ~1200C at these pressure conditions (Kubo et al., NGEO2010). We are also preliminarily conducting some LHDAC experiments, however we have not observed lingunite at least ~1400C. Further studies on the formation process of lingunite are needed to solve this problem, which may lead to construct another P-T-t shock indicator.