Separation of Mo, W and HFSEs from rock samples for the study of isotope anomalies in meteorites

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Recent innovations in mass spectrometry have enabled detection of small isotope anomalies in some heavy elements present in a variety of meteorites. To make highly-precise and "accurate" isotope analysis, chemical separation of the target element from various types of meteorites must be developed from the following standpoints: 1) Achieve of nearly 100% recovery to avoid mass fractionation during chemical separation. 2) Complete removal of unwanted elements that can interfere with isotope analysis. 3) Maintain high sample/blank ratios. 4) Simultaneously separate as many elements as possible from a single sample. The last point is important not only to preserve precious meteorites, but also for performing multi-elemental isotope analysis on heterogeneous samples. In this study, we have developed a chemical separation method for Mo, W and HFSEs (High Field Strength Elements; e.g., Zr, Hf) from meteorite samples, all of which are intriguing elements for the study of isotope anomalies in the early solar system. We also show our prelimiary analysis of Mo isotope compositions in bulk chondrites and their acid leachates.

The separation method consists of a two-stage column chemistry using anion exchange resin (BioRad AG1X8). We have evaluated the performance of our technique by using a synthesized multi-element solution and some terrestrial rock samples decomposed by HF. A quadrupole-type ICP-MS (*ThermoFisher X SERIES II* at Tokyo Tech.) was used to determine the elution profile, as well as the recovery yield of Mo during the column chemistry. Molybdenum isotopes were analyzed by N-TIMS (TRITON-*plus* at Tokyo Tech).

In the first column, HFSE, W and Mo were successively eluted by 9M HCl-0.05M HF, 9M HCl-1M HF, and 6M HNO_3-3M HF, respectively. Unwanted elements in the Mo fraction (Zn, Nb and trace Ru) were further separated in the second column. The column size and total amount of acids were dramatically reduced compared to previous techniques. The Mo recovery was 94.5 ± 2.9 % in the first column and 101.3 ± 5.0 % in the second column. By applying this technique, we have determined Mo isotope compositions in bulk samples of Murchison (CM2) and Allende (CV3), as well as their acid leachates. The Mo isotope anomalies in bulk Murchison and a leachate indicate deficits of *s*-process Mo isotopes, consistent with previous studies [1, 2]. In contrast, anomalies observed in bulk Allende and its leachates are enigmatic, which may require a reassessment of the isotopic compositions of end-member components calculated by current nucleosynthetic theories.

[1] Burkhardt et al. (2011a) *EPSL* **312**, 390-400. [2] Burkhardt et al. (2011b) *LPSC* **42**, #2592.

Characterizing the cessation of arc-normal mid-crust extrusion, NW Nepal Himalaya

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The metamorphic and anatectic core of the Himalaya, the Greater Himalayan Sequence (GHS), has been hypothesized to represent exhumed mid-crustal material via a channel flow model [1 and references therein]. Characterizing the cessation of this lateral mid-crustal extrusion is integral in providing a comprehensive understanding of mid-crustal flow during orogenesis.

Field mapping, structural and microstructural analysis, geochronology, and thermochronology confirm the existence of the Gurla-Mandhata-Humla fault, an orogen-oblique strike-slip dominated fault in the High Himalaya of northwestern Nepal. Detailed across-strike transects reveal shallow-dipping mylonitic foliations and strongly-developed shallow plunging mineral stretching lineations interpreted to represent the terminal stages of arc-normal directed extrusion of mid-crustal material, and onset of orogenic extension [2]. Furthermore, late-stage deformation along this fault system overprints the GHS and its upper bounding fault, thus confirming a cessation of and transition from extruding GHS to subsequent arc-parallel deformation. A study of this fault system therefore provides documentation of the final stages of arc-normal directed extrusion of mid-crustal material.

The shear zone is characterized at upper structural levels by well-developed type-1 cross-girdle quartz c-axis fabrics and symmetric a-axis fabrics, indicating plane strain conditions. C-axis fabrics transition to type-2 cross girdles at ~ 1.2 km below the fault, suggesting an ostensible contribution of constrictional strain at depth. This deviation towards constriction is consistent with measured quartz a-axes, which show a progression towards upright cleft girdle patterns at similar depths. Quartz c-axis opening angles and quartz and feldspar recrystallization mechanisms show a progressive increase in deformation temperatures from ~ 350°C along the zone of maximum strain, to upwards of ~ 630°C at depths greater than ~ 5.5 km below the fault. Abundant asymmetrical fabric elements and conjugate shear bands in conjunction with a calculated mean kinematic vorticity number of 0.60 (c. 58% pure shear) attest to an important contribution of pure shear. U-Th-Pb in situ monazite geochronology, U-Pb zircon geochronology, and $^{40}Ar/^{39}Ar$ muscovite thermochronology reveal crystallization, decompression melting, and cooling within ≤ 7 Myr.

These data indicate that the final stages of the extruding mid-crust are characterized by a particularly high vertical gradient in deformation temperatures, deviations from plane strain at depths, and a significant contribution of pure shear. Furthermore, chronological data suggest that cooling and cessation of arc-normal extrusion of the mid-crust occurred within a geologically confined period.

[1] Godin et al. (2006) *Geol. Soc. Spec. Publ.* **268**, 1-23. [2] Murphy & Copeland (2005) *Tectonics*. **24**. TC4012, doi:10.1029/2004TC001659.