

MOLYBDENUM ISOTOPIC EVIDENCE FOR THE EVAPORATION LOSS OF MO IN CK CHONDRITES AND IMPLICATIONS FOR THEIR FORMATION MECHANISM. Y. Zhang¹ and L. Qin^{1*},

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Introduction: Chondrites are often regarded as the building blocks of the Earth. However, arguments have been raised when comparing the volatile and refractory components between chondrites and the Earth[1,2]. The Earth exhibits more affinity with carbonaceous chondrites in volatiles[1] and enstatite chondrites in refractory elements[2]. Chondrites have been subjected to a variety of planetary and geological processes such as volatility, thermal metamorphism and changes of oxygen states[3-5] that could alter their original composition. Discriminating these process could help to understand the chemical evolution of the early solar system including the mechanism of the volatile accretion.

In recent years, Mo stable isotopes have been increasingly used for tracking various planetary and geological processes[6-8]. Molybdenum in different valence states behave distinctively during planetary and surface processes, which often result in Mo isotopic fractionation between Mo species with different valence states[7]. In addition, Mo in high valence would easily get evaporated under oxidizing conditions[9]. The evaporation usually accompanied with a large isotopic fractionation as a result of a Rayleigh loss.

Studies on chondrites have shown a uniform Mo mass-dependent isotopic composition except for one CM (Murchison) and one CK (Karoonda) [6]. However, the fractionation mechanisms are not fully understood. Here we present new Mo isotopic data for a set of chondrites especially for CKs to further constrain the early evolution in the chondrite parent bodies.

Samples and Methods: Chondrites especially CKs with varying degrees of thermal metamorphism were selected for Mo isotopic measurements. Other chondrites were selected including OCs and ECs with petrology types up to 7 for comparison. The weathering degrees of all the studied meteorite samples are relatively low to minimize the influence of weathering.

After complete sample digestion, one aliquot was taken and was spiked with ⁹⁷Mo-¹⁰⁰Mo spike. Both the spiked and unspiked aliquot were subjected to a three-step ion exchange procedure. After the purification procedure, the Mo isotopic compositions of the samples were measured using MC-ICP-MS, and the

mass dependent isotopic fractionation was calculated from both spiked and unspiked measurements of the samples, and are expressed in $\delta^{98}\text{Mo}$ notation relative to the NIST SRM 3134 standard.

Results: The results showed that the Mo isotopic fractionation of most chondrites fall within the range of the chondritic uniform reservoir(CHUR) consistent with previous study[6], which is also identical to the estimation of the BSE from the study of the komatiites and the mantle xenoliths[8]. However, all CK chondrites exhibit varying degree of positive Mo isotopic fractionation compared to CHUR, and the magnitudes of the enrichment in heavy Mo isotopes increases with the petrological degrees (Fig. 1).

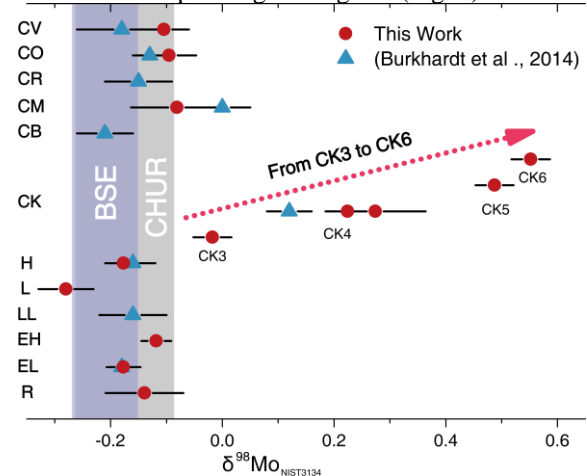


Fig. 1: $\delta^{98}\text{Mo}$ for chondrites. The gray region shows the Mo isotopic composition of CHUR defined by this work and by literature[6] ($-0.18\% \pm 0.08, 2\text{SD}$).

This relationship had not been observed in other classes of meteorites such as EHs and ELs, although samples from the latter also cover a wide range of the metamorphic degree. CVs showed no Mo isotopic fractionations either. Moreover no obvious correlation was observed between the Mo isotopic compositions and the Mo contents for CK chondrites, indicating that the variation in Mo isotopic composition cannot be explained solely by two end member mixing.

Discussion: The isotopic fractionation was unlikely to be generated from the elemental redistribution between different components of the chondrites during thermal metamorphism as Mo migration and redistribution between minerals or rocks

could not induce the large isotopic fractionation observed in CKs without the liquid water[8]. Previous work proposed that mixing between the isotopically distinct metal and matrix could explain the positive isotopic deviation in the CK chondrite Karoonda[6]. However, the large isotopic variation in metal-less CKs requires the isotopic compositions of the metal to be significantly different from the matrix. This is also not consistent with the observed Mo isotopic compositions of metal-rich chondrites such as CV and CO.

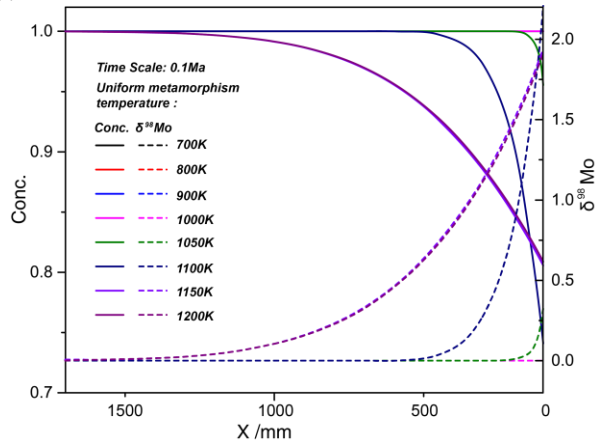


Fig. 2: Numerical modeling results of the depth profile of Mo concentration and isotopic composition for a spherical body induced by Mo evaporation in vacuum. The solid lines show Mo concentration profiles and the dash lines show Mo isotopic fractionation profiles.

Molybdenum in hexavalent state was volatile[9]. The oxygen fugacity of CKs is in the range of FMQ +2 - FMQ +4.5[10], but from the thermodynamic calculation results, the oxygen fugacity required for the transformation from Mo(IV) to Mo(VI) is lower than FMQ. Besides, due to the high oxygen fugacity, metal no longer exists in the CKs, so that a large percent of Mo cannot be in zero valence state either. Therefore the Mo in CKs is most likely dominated by Mo(VI). Given the high metamorphism temperatures of CKs, Mo lost could have occurred.

Numerical modeling was applied to simulate Mo loss in a spherical body at different temperatures. The depth profile of Mo isotopic fractionation induced from evaporation is controlled by the diffusion of Mo from the core to the surface (Fig. 2), with the Mo isotopic fractionation increasing from the core to the rim. Further, with the temperature increasing, the concentration of Mo decreases, and the magnitude of the isotopic fractionation increases. However in an onion cell model, where the parent body of chondrites is heated by the decay of the short-lived nuclides such as ^{26}Al , this would generate a hot core with a cold shell[4]. In most cases for chondrites the shell was

colder than 900K and was inadequate to produce a resolvable Mo isotopic fractionation. Thus, the new Mo isotope evidence points to the evaporation of Mo during impact heating[5] or the solar radiation heating[11]. Previous petrologic research on CKs revealed that the redox of CKs during the impact was reducing[3]. Therefore, oxidation of CKs most probably occurred after the impact event. This suggests that CKs gained water in the heliocentric orbit.

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