THE ABUNDANCE OF MOLYBDENUM IN LUNAR SAMPLES, NEW EVIDENCE FOR A LUNAR METAL CORE.

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Two theories for the origin of the Moon are being actively considered, a terrestrial origin involving material ejected from the Earth by a large impact, or an independent origin by accretion of protoplanetary material in geocentric orbit. New data on the concentration of molybdenum in the mantle of the Earth (1) and in lunar rocks confirm that most siderophile elements in lunar crustal rocks and lunar basalts derived from the interior have significantly lower concentrations than in the Earth's mantle and much lower concentrations compared to chondritic meteorites. A small amount of data on Mo abundances in lunar samples was reported in the original investigations of the Apollo 11 and 12 samples, but the data ranged over almost 3 orders of magnitude. Our data (Fig. 1) confirms the low Mo concentrations reported by Taylor et al. (2). The Mo/Nd ratio in lunar samples (0.0016, Fig. 1) is a factor of 30 lower than the Mo/Nd ratio in terrestrial samples (0.043, 1), and a factor of 1,200 lower than in C1 chondrites. These new results rule out the fission origin for the Moon as originally advocated by Ringwood and Kesson (3), which assumed the Moon and the Earth's mantle have similar concentrations of siderophile elements.

A modified terrestrial origin for the Moon has been suggested by Wänke et al. (4), to explain their observation that Co and P are more depleted in lunar samples than in the Earth's mantle. They suggest that the Moon formed from the Earth's mantle (already depleted in siderophile elements relative to C1, e.g. ref. 3), but segregation of metal within the Moon further lowered the concentrations compared to the Earth's mantle. Ringwood's current ideas conform to this model (5, Ringwood, personal communication, 1983). From the terrestrial siderophile element concentrations, the concentrations in the lunar samples (Fig. 2) can be reached by segregation of only 0.15% metal at 10% partial melting. At low degrees of partial melting, the incompatible siderophile elements (all elements in Fig. 2 except Co and Ni) are excluded from the solid silicates, the concentrations in the metal become higher, therefore less metal is needed to cause a depletion. For total melting of the silicates as much as 1% metal would be required to achieve the observed W, P, Mo and Re depletions. For total melting conditions Co and Ni would be depleted much more than indicated in Fig. 2, because there would be no silicate minerals to retain these elements.

For an independent origin of the Moon, segregation of a small metal core could explain the concentrations of siderophile elements in lunar rocks (6). Starting with chondritic concentrations and assuming a metal content of 5.5% at 9% partial melting of the silicates, the calculated depletions match the observed depletions (Fig. 2). Only the calculated depletion for P is not as great as required, but P may have become depleted in proto-lunar material because of volatility. Metal contents smaller than 5.5.% can also explain the depletions of W, Mo and Re if equilibrium occurred at smaller degrees of partial melting (7). For a 2% core about 1% partial melting is required. Segregation of metal at low degrees of partial melting is physically difficult, but it depends on the grain size and melting temperature of the metal, as well as the physical properties of the silicate assemblage. The depletion of compatible siderophile elements Co and Ni cannot be explained by metal contents smaller than 5.5% unless the metal/silicate partition coefficients are greater than assumed, or the Ni/Fe and Co/Fe ratios are smaller than C1 chondritic

ratios. Unfortunately, the depletion of Ni in the Moon due to segregation of metal is very poorly constrained. A small metal core containing less than 25% Ni is, however, consistent with the 150 ppm Ni content of the low Ti-mare basalts (8). The fractionations of Co, Ni and W do indicate that metal was absent from the source regions of lunar basalts, requiring the metal segregation event to have occurred very early in lunar history (3, 9).

The Mo data support evidence from other siderophile elements that the Moon almost certainly contains a metal core or pools of segregated metal. A clear cut answer to the origin of the Moon is not yet available, but the constraints on possible models are much tighter because of the new data.

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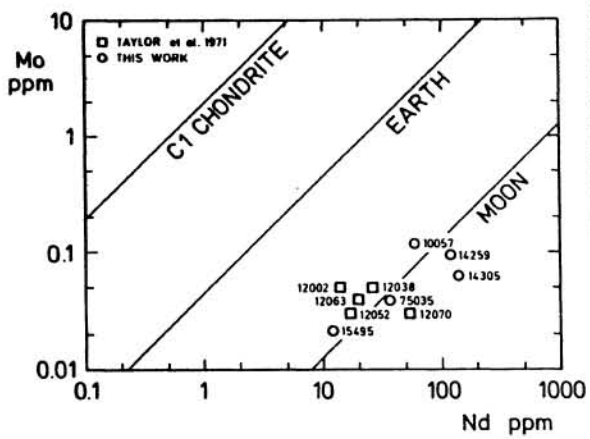

Fig. 1

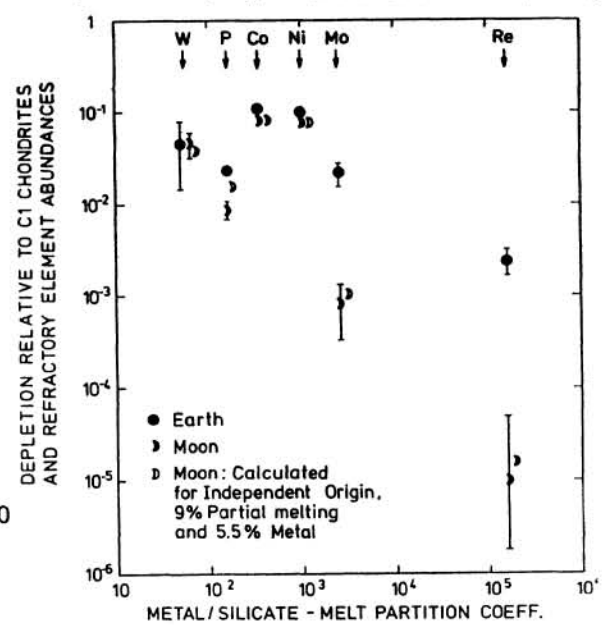

Fig. 2

Fig. 1 Mo and Nd concentrations in lunar samples. The new Mo concentrations are 129 ppb 10057, 125 ppb 14259, 81.4 ppm 14305, 21.5 ppb 15495, 39.3 ppb 75035, with errors approximately 15%. A correction for the meteoritic component in the highlands samples, based on Ir content, gives the plotted intrinsic Mo concentrations: 94.7 ppb 14259, 62.2 ppb 14305.

Fig. 2 The depletion of W, P, Co, Ni, Mo and Re in the Earth and Moon plotted as a function of the metal/silicate-melt partition coefficient for each element. Depletion data from this work and (1, 9, 10, 11, 12). The following metal/silicate-melt partition coefficients have been used in the calculations: D(P)=160 (7), D(W)=54 (13), D(Mo)=2,500 D(Ni)=1000 and D(Co)=350 (14).