ACCRETION AND CORE FORMATION IN THE EARTH Valerie J. Hillgren, Christopher J. Capobianco, and Michael J. Drake, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.

Introduction. Wänke [1,2] has proposed a heterogeneous accretion model to account for the siderophile element abundance pattern in the Earth's mantle. In this model, the first material accreting to form the Earth is highly reduced, and all Fe and other siderophile elements are metallic and, thus, separate to form the core. The last 10-20% of material is progressively more oxidized allowing moderately siderophile elements to remain in the mantle. The final 1% of material is so oxidized that metallic Fe is unstable, and therefore, the noble siderophile elements from this portion remain in the mantle. The progressively more oxidized material implies a progressively more Ni-rich metal phase (*i.e.*, Fe is more readily oxidized than Ni). Thus, we have measured the partition coefficients of moderately siderophile elements in systems containing basaltic liquid, sulfur bearing metallic liquid, and nickel bearing metal.

We have formerly used these results to conduct a simple test of the heterogeneous accretion model [3]. We treated core formation as occurring in two discrete events. The first event occurred after the initial 80% of the Earth accreted, and this material was so reduced that all siderophile elements went into the core. The second core forming event occurred after the last 20% of material was accreted, and all siderophile elements were present in the mantle in 0.2 x CI abundances. We assumed that the metal which separated during this phase was pure Ni. We then used mass balance and our partition coefficients to determine the amount of metal that must be separated in order to decrease the abundance of Mo from 0.2 x CI to its inferred modern value of 0.064 x CI. We found that an implausible negative fraction of metal would have to be separated. However, Jones and Drake [4] conducting a similar test for the case of nearly pure Fe metal had found that such a minute amount of metal would have to be subtracted that the other moderately siderophile elements would not be affected. We, thus, concluded that perhaps an intermediate Ni content in the metal could account for the Mo abundance. We have now also measured partition coefficients for some siderophile elements in systems where the metal consists of 50% Ni and 50% Fe, and incorporated these partition coefficients as well as those for pure Ni into core forming models involving partial melting of the silicates.

Modeling. We have used simple mass balance and our partition coefficients (Table 1) to calculate the abundances of Ni, Co, Mo, and W in the primitive mantle of the Earth for various core forming scenarios. For solid silicate/liquid silicate partition coefficients we have chosen to utilize those reported in Jones and Drake [4] instead of those reported by McFarlane *et al.* [6] in order to have a set of internally consistent partition coefficients. Both our partition coefficients and Jones and Drake's were measured at 1 bar, whereas those of McFarlane *et al.* were measured at very high pressures. The degree of partial melting of the silicates in our models was varied form 10-100%. In all models, the metal was 30% molten.

We again treat core formation as occurring in two discrete events. The first event occurs after some percentage of the Earth accreted of extremely reduced material, and all the siderophile elements enter the core. The second event occurs after the rest of the Earth accretes, and either pure Ni metal separates or metal consisting of 50% Ni and 50% Fe separates to go to the core. The material added prior to the second core forming event is assumed to be of chondritic composition nominally consisting of 70% silicates and 30% Fe-Ni metal. The metal is assumed to be 90% Fe and 10% Ni. Thus, if the incoming chondritic material were so oxidized that only Ni were metallic, then the material is actually 97% silicates and 3% metallic Ni.

Results. Figures 1 and 2 show the resulting abundance patterns of Ni, Co, Mo, and W for some sample calculations compared to their known abundance pattern [4,5]. Figure 1 illustrates our original test case, *i. e.*, a core forming event occurs after the first 80% of the Earth accretes and removes all siderophile elements from the mantle, and then a second core forming event involving pure Ni metal occurs after the last 20% of the Earth is accreted. There is little difference between the cases involving different degrees of partial melting of the silicates (in fact, they have all nearly plotted on top of one another). We also varied the percentage of liquid metal and found essentially no effect on the final abundance pattern. This scenario seems able to account for the approximately chondritic Ni to Co ratio observed in the mantle, especially at lower degrees of partial melting. However, in no case is it able to account for the depletion in Mo.

Figure 2 illustrates the results of a model where again the first 80% of the Earth is very reduced. The second core forming event occurs after the last 20% of the Earth accretes and involves metal that consists of 50% Ni and 50% Fe. In this scenario the degree of partial melting of the silicates plays an important role in the final abundance pattern. No calculated pattern comes close to the observed abundance pattern of Ni, Co, Mo, and W. For high degrees of partial melting, the model Mo abundance is close to the observed abundance, but Mo is extremely over depleted for low degrees of partial melting. Tungsten is fairly insensitive to the degree of partial melting, and the model predicts abundances similar to those observed. Nickel and Co are much more depleted in the model than observed, and their ratio is not chondritic. If the partition coefficients of McFarlane *et al.* for Ni and Co are used in this model, Ni and Co become less sensitive to degree of partial melting, but they are still over depleted and in a non-chondritic ratio.

None of the models we have tested so far are able to account for the observed abundances of Ni, Co, Mo, and W in the Earth's primitive mantle. However, the similarity between the patterns for the second scenario and the observed pattern suggests that a Ni content of the metal content somewhere between 50 and 100% may produce the observed pattern. The models explored here are all very simple, and we are currently investigating more complex models with the Ni content in the metal changing through time. Any model or scenario for core formation must also account for the abundances of other siderophile elements, not just Ni, Co, Mo, and W.

References. [1] Wänke, H. (1981) *Phil. Trans. R. Soc. Lond.*, **A303**, pp.287-302. [2] Wänke, H. and G. Dreibus (1988) *Phil. Trans. R. Soc. Lond.*, **A325**, pp. 545-557. [3] Hillgren, V. J., C. J. Capobianco and M. J. Drake (1990) *Meteoritics*, in press [4] Jones, J. H. and M. J. Drake (1986) *Nature*, **322**, pp. 221-228. [5] Simms, K., H. E. Newsom and E. S. Gladney (1990) in *Origin of the Earth* (H. E. Newsom and J. H. Jones, editors), pp. 291-317. [6] McFarlane, E. A., M.J. Drake, and C. Herzberg (1991), this volume.

Table 1: Partition Coefficients Used in Models

		Metal 100% Ni		Metal 50% Ni/ 50% Fe	
Element	$D_{(SS/LS)}$*	$D_{(LM/LS)}$	$D_{(SM/LS)}$	$D_{(LM/LS)}$	$D_{(SM/LS)}$
Ni	10	30	33	1800	2200
Co	3	0.8	1.3	130^l	260^l
Mo	0.01	0.01	0.03	200^l	220^l
W	0.01	0.01^u	0.01^u	0.25	1.6

LS=liquid silicate, SS= Solid silicate, LM=liquid metal, SM=solid metal; * values taken from [4]; u=upper limit; l=lower limit