SIDEROPHILE ELEMENT DEPLETION IN THE ANGRITE PARENT BODY (APB) MANTLE: DUE TO CORE FORMATION?

K. Righter, Mailcode KT, NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058; kevin.righter-1@nasa.gov.

Introduction: The origin of angrites has evaded scientists due in part to unusual mineralogy, oxidized character, and small numbers of samples [1,2]. Increased interest in the origin of angrites has stemmed from the recovery of ~10 new angrites in the past decade [3]. These new samples have allowed meteoriticists to recognize that angrites are compositionally diverse, old, and record very early differentiation [4]. Also, a magma ocean has been proposed to have been involved in APB early differentiation [5], but this remains untested for siderophile elements which are commonly cited as one of the main lines of evidence for magma oceans on the early Earth, Moon, Mars and eucrite parent body (e.g., [6]). And recent suggestions that angrites may [7] or may not [8] be from Mercury have also peaked interest in these achondrites.

Given all of this background, a detailed understanding of the early differentiation process is desired. Previous efforts at examining siderophile element (SE) concentrations with respect to core formation processes in the APB [9] have not resulted in any definite conclusions regarding segregation of a metallic core. The goal of this study is to summarize what is known about SE concentrations in the suite, estimate depletions of SE compared to chondrites, and apply metal/silicate experimental partition coefficients to assess whether the APB had a core.

Siderophile element concentrations in the APB: There are many rock types in the angrite suite, including breccias (NWA 4801; [3]) or course grained angrites that may be metamorphosed or cumulates (e.g., NWA 2999 or 4590; [3]). To estimate concentrations of SE in the APB mantle, only those with ophitic or subophitic basaltic textures are considered. In addition, this initial modeling will only include the refractory SE, Ni, Co and W.

Siderophile element concentrations for angrites are shown in Figures 1 to 3, and are compared to data from Earth, Mars and the eucrites (references from [17]). The depletion of Ni is similar to that of the shergottites, and extension of the Ni–(MgO+FeO) trend to mantle-like values results in a Ni concentration of ~300 ppm (Fig. 1). Similarly for Co, extension of the trend results in a Co concentration of ~80 ppm (Fig. 2). Studies of Hf-W isotopes have resulted in new bulk W data for angrites [13], and together with previous studies define a depletion intermediate between shergottites and eucrites (Fig. 3). This results in a mantle concentration of ~ 50 ppb.

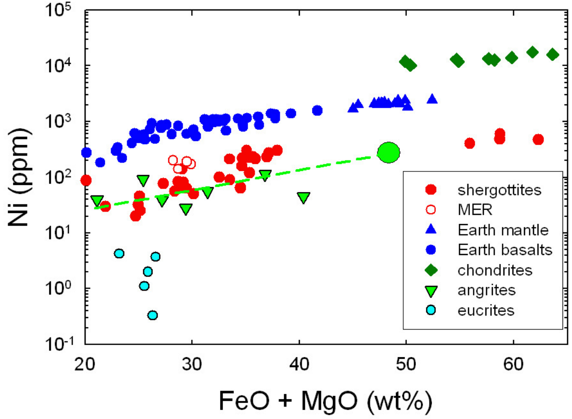

Fig. 1: Ni (ppm) vs. MgO+FeO (wt%) for angrites, compared to terrestrial basalt, peridotite, shergottites, eucrites (all from [17]), and chondrites [16]. Data for angrites from [10-15].

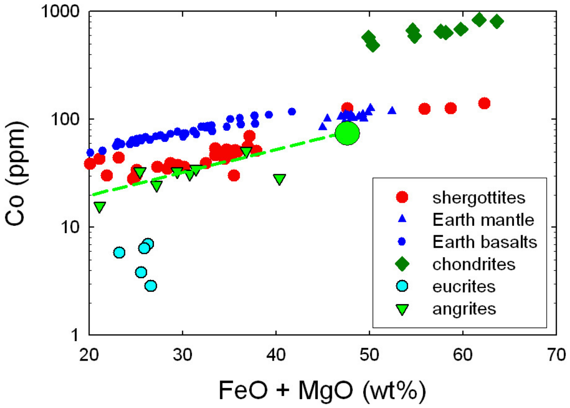

Fig. 2: Co (ppm) vs. FeO+MgO (wt%); sources as Fig. 1.

Metal-silicate partitioning: Because the goal of this study is to identify conditions whereby the APB may have segregated a metallic core, it is necessary to be able to predict D(M/S) as a function of the controlling variables – temperature, pressure, oxygen fugacity, and silicate and metallic melt compositions. Here the expressions of [18] are used, since they have been calibrated across a wide range of possible conditions.

Metallic core in the APB?: With the estimates of mantle concentrations, the partition coefficient expressions, and assuming a bulk composition of CV chondrites [16], we can assess whether the APB has a core and how large it might be. Two different scenarios are considered, based on assumptions about fO_2 in the APB:

Scenario 1: If the APB mantle has the same fO_2 as angrite basalts [2], IW+1, the core would have to be large to explain the observed depletions, since at this high fO_2, M/S partition coefficients would be smaller than usual. Consideration of a simple model shows that if the core size is fixed at 60 mass%, the Ni, Co and W concentrations can be explained by metal-silicate equilibrium between basaltic melt (partially molten mantle) and C-bearing FeNi metallic liquid core at 1700 K, 1 bar and IW+1. This scenario seems unlikely however, because having a large core at oxidized conditions is counter-intuitive.

Scenario 2: It is possible that the APB mantle was more reduced than IW+1, and the basalts became oxidized upon degassing and eruption. Several angrites have vesicles [19] indicating the presence of a C-bearing gas, and carbon (graphite) is known to control fO_2 such that only a small amount of pressure can cause oxidation to above the IW buffer. Therefore, if the APB mantle was originally reduced, near IW-1, the core would have to be relatively small to produce the Ni, Co and W depletions observed since the M/S partition coefficients would be larger at these conditions. Consideration of a simple model shows that if the core size is fixed at 8 mass%, the Ni, Co and W concentrations can be explained by metal-silicate equilibrium between peridotite mantle and a C-bearing FeNi metallic liquid core at 2173 K, 5 kb, and IW-1. This pressure is consistent with a core near the center of a body a few hundred km in radius.

What about volatile element depletion?: One of the most elusive aspects of the APB is its volatile element depleted nature. Na, K, and Rb are all depleted relative to CI chondrites by a factor of 250-300 (when normalized to Sm, La and Sr, respectively). Gallium is a volatile siderophile element and when corrected for volatility, it exhibits no depletion in the APB mantle. In either scenario 1 or 2 above, the conditions would predict a D(M/S) for Ga that is << 1, indicating that Ga is satisfied by either scenario. The same may also be true for P and Cr.

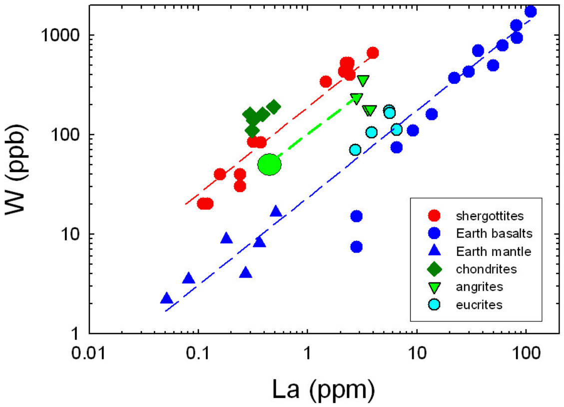

Fig. 3: W (ppb) vs. La (ppm); sources as Fig. 1.

Conclusions: Scenario 2 seems more likely since having a small core under reducing conditions is expected, and the model also accounts for the presence of volatiles in the APB parent body. It is important to understand that the results of these calculations are not unique, and there may be other conditions which can satisfy siderophile element depletions. Additional modeling should be done to test various conditions.

References: [1] Floss, C. et al. (2003) GCA 67, 4775-4789; [2] McKay, G.A. et al. (1994) GCA 58, 2911-2919; [3] Irving, A.J. and Kuehner, S. (2007) Workshop Chron. Met. Early Solar Sys., Hawaii. LPI Contrib. No. 1374, p.74-75; [4] Amelin, Y. (2007) LPSC XXXVIII, LPI Contrib. No. 1338, #1669; [5] Greenwood, R.C. et al. (2005) Nature 435, 916-918; [6] Righter, K. (2003) Ann. Rev. Earth Planet. Sci. 31, 135-174; [7] Irving, A.J. et al. (2005) Amer. Geophys. Union, FM 2005, #P51A-0898; [8] Ruzicka, A. and Hutson, M. (2006) MaPS 41, #5080; [9] Jones, J.H. et al. (1988) Meteoritics 23, 276-277; [10] Warren, P.H. et al. (1995) AMR 20, 261-264; [11] Kurat, G. et al. (2004) GCA 68, 1901-1921; [12] Mittlefehldt, D.W. and Lindstrom, M.M. (1990) GCA 54, 3209-3218; [13] Mittlefehldt, D.W et al. (2002) MaPS 37,345-369; [14] Markowski, A. et al. (2007) EPSL 262, 214-229; [15] Jambon, A. et al. (2005) MaPS 40, 361-376; [16] Newsom, H. (1995) in Global Earth Physics (ed. Ahrens, T. J.), AGU Ref. Shelf vol. 1, 159–189; [17] Righter, K. et al. (2006) Amer. Mineral. 91, 1643-1656; [18] Righter, K. and Drake, M.J. (1999) EPSL 171, 383-399; [19] McCoy, T.J. et al. (2006) EPSL 246, 102-108.