THE NICKEL CONTENT OF THE LUNAR CORE; H.E. Newsom, Dept. of Geology and Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131

The nickel content of the lunar core, which has a large effect on the metal/silicate partition coefficients between the core and the lunar mantle, may be an important constraint on the origin of the Moon. Seifert et al. [1] have applied their results of important high pressure partitioning experiments for Fe, Ni and Co to derive the Ni content of the lunar core. Their Ni content for the lunar core is a very high Ni value of 38 to 44 wt%. Because a Ni-rich core has much lower metal-to-silicate partition coefficients, Ni contents much greater than 15 wt% would not be consistent with the observed siderophile depletions and the small size of the lunar core [2,3,4]. Therefore, this conclusion supports the formation of the Moon largely out of material from the Earth's mantle as argued by Ringwood and Seifert [5] and Ringwood [6] on the basis of the work now published by Seifert et al. [1]. The application of these experimental data to the Moon, however, contains important flaws that invalidate their conclusion. I will discuss two points: first that the authors have made a fundamentally wrong assumption in their application of the experimental data to the Moon, and second that their data can be used to show that the lunar core probably had Ni contents of less than 25 wt% [7].

Seifert et al. [1] carefully determined experimentally the composition of olivine in equilibrium with Apollo 15 Green Glass and calculated the Ni content of metal in equilibrium with these olivines. The Ni content used for the calculation was that of Apollo 17 Green Glass, presumably because this was the highest value available. Assuming a Ni content of 188 ppm they derive Ni contents for metal in equilibrium with the source region of the Green Glass of 38 to 44 wt%, including some uncertainties.

The key problem with this calculation is the assumption that the Apollo 15 Green Glass represents melts derived from a primitive lunar mantle. They specifically conclude: "Since this Green Glass composition is thought to approximate to that of a primitive melt from the lunar mantle, this metal composition is that which would separate under conditions of thermodynamic equilibrium from the lunar mantle to form the small lunar core." They cite Ma et al. [8] regarding the source of the Green Glass, however this reference concludes: "the green glasses ... were derived by partial melting of *fractionated cumulate source materials* formed from a magma ocean ..." (italics from Ma et al., 8), due to the presence of a Eu anomaly in the glasses. A similar conclusion has been reached by Hughes et al. [9]. The derivation of Green Glasses from cumulates as opposed to a primitive lunar mantle has important implications for the Ni content of the lunar metal core as demonstrated by a few calculations.

Assuming that the Apollo 15 Green Glasses were derived by small degrees of partial melting (<7%), the Ni content of the melts could also closely represent the Ni content of the magma from which the cumulate source region crystallized, i.e. the magma ocean. Based on experimental petrology the MgO/(MgO + FeO) ratio in the olivines from the source region is very high, consistent with the source being an <u>early</u> cumulate from the magma ocean [10]. The problem is to link the Ni content of the magma ocean with the Ni content of the metal in the lunar core. If the magma ocean was in direct equilibrium with the lunar core, the conclusion of Seifert et al. would be correct. This is unlikely, however, because the metal separation probably occurred at some moderate degree of partial melting of the lunar mantle, yet the magma ocean probably represents a high degree of melting of the lunar mantle. This would be true if the core formed in a Moon that accreted in situ, or in a precursor planet that collided with the Earth and contributed most of the material that now makes up the Moon.

For a quantitative example, assume that a large portion of the Moon (or precursor planet) experienced metal segregation at 10% partial melting, and then the silicates were completely melted in the Moon to form a magma ocean with 188 ppm Ni. Using the equilibrium melting equation and assuming an olivine solid with the partition coefficient for Ni of 4.4 obtained by Seifert et al. [1], the Ni content of the liquid at 10% melting will be 46 ppm because most of the Ni will be locked up in the solid olivine. (Total melting of the remaining olivine brings the Ni content of the melt back up to 188 ppm.) Using the range of metal/silicate partition coefficients for Ni obtained by Seifert et al. [1], the Ni content of the metal in equilibrium with the 46 ppm Ni melt will be 9.5 wt% to 11 wt% Ni.

If the magma ocean formed by partial melting instead of total melting, the Ni content of the metal will be larger, but not as large as calculated by Seifert et al. [1]. For example, assuming that the bulk Ni content of the Moon is 470 ppm [11], a value for the magma ocean of 188 ppm Ni implies that the magma ocean represents a 56% partial melt. Assuming that metal segregated at 10% partial melting, the Ni content of the liquid at this stage would be 116 ppm, therefore, metal in equilibrium with this liquid would contain 24 to 27 wt% Ni. This Ni content could be consistent with core formation in a large impactor which contributed most of the lunar material, where the size of the core is not well constrained.

An additional argument against Ni-rich metal in equilibrium with the lunar silicates is the reduced oxidation state of the Moon. The oxidation state of the Moon is below the Fe-FeO buffer and characterized by the lack of ferric iron, such that lunar basalts crystallized at oxygen fugacities which were 4 to 5 orders of magnitude lower than those of terrestrial basalts at equivalent temperatures [12]. If lunar silicates had equilibrated with Ni-rich metal, lunar oxygen fugacities would be much higher. The conclusion of Seifert et al. that the lunar metal core which was in equilibrium with lunar silicates contained very high Ni contents is not supported by the available data.

References: [1] Seifert S., O'Neill H. St. C., and Brey G. (1988) Geochim. Cosmochim. Acta 52, 603-616. [2] Newsom H.E. and Drake M.J. (1982) Nature 297, 210-212. [3] Newsom H.E. (1984) EOS, Transactions A.G.U. 65, 369-370. [4] Newsom H.E. (1986) In Origin of the Moon (eds. Hartmann, W.K., Phillips, R.J. & Taylor, G.J.) 203-229 (Lunar and Planetary Institute, Houston). [5] Ringwood A.E. and Seifert S. (1986) In Origin of the Moon (eds Hartmann, W.K., Phillips, R.J. & Taylor, G.J.) 249-278 (Lunar and Planetary Institute, Houston). [6] Ringwood A.E. (1986) Nature 322, 323-328. [7] Newsom H.E. (1989) Geochim. Cosmochim. Acta (submitted). [8] Ma M.S., Liu Y. and Schmitt R. A. (1981) Proc. Lunar Sci. Conf. 12th, 915-933. [9] Hughes S.S., Delano J.W. and Schmitt R.A. (1988) Geochim. Cosmochim. Acta 52, 2379-2392. [10] Longhi J. (1978) Proc. Lunar Planet. Sci. Conf. 9th 285-306. [11] Delano J.W. (1986) In Origin of the Moon (eds. Hartmann, W.K., Phillips, R.J. & Taylor, G.J.) 231-248 (Lunar and Planetary Institute, Houston). [12] Basaltic Volcanism Study Project (1981) Basaltic Volcanism on the Terrestrial Planets, Pergamon, New York.

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