GEOCHEMISTRY OF SOME VOLATILE SIDEROPHILE AND LITHOPHILE ELEMENTS IN THE LUNAR HIGHLANDS. J.W. Delano and A.E. Ringwood; Research School of Earth Sciences; Australian National University; Canberra, A.C.T. 2600, Australia.

It has been shown elsewhere [1] that the major element composition of the magma from which the lunar highland crust originated (PLC magma) was similar to that of terrestrial oceanic tholeiites, except for depletion of the two most volatile elements, Na and Si. Moreover, the abundances of the rare earth elements were similar in both cases [1,2]. In a companion abstract [3], we have studied the abundances of seven siderophile elements (W,Ni,Co,P,Au,S, Se; Set 1 in Table 1) in the PLC magma, and concluded (a) that large proportions are indigenous to the moon and (b) that the abundances in the PLC magma were similar (i.e. within a factor of 2) to those in terrestrial tholeiitic magmas.

The Set 1 siderophile elements (Table 1) are characterised by relatively low volatilities, either in absolute terms (W,Ni,Co,P,Au) or in nebula environments where low hydrogen fugacities (S,Se) may have prevailed [1]. As an extension of the discussion, we shall consider the calculated abundances of some relatively volatile, siderophile elements (As,Cu,Ga,Ag,Sb,Ge; Set 2 in Table 1) in the PLC magma as compared with terrestrial oceanic tholeiites. Since it is well-known that lunar rocks are depleted in volatile elements relative to corresponding terrestrial samples [e.g. 4], we have also calculated the abundances of five moderately volatile, lithophile elements (Li,Mn,Na,K, Zn; Set 3 in Table 1) in the PLC magma in order to readily distinguish this effect of depletion controlled by volatility.

The abundances of these Set 2 siderophile elements (Table 1) in the PLC magma have been calculated using the simple two-component mixing model discussed by Delano and Ringwood [3]. This model assumes the Apollo 16 highlands to be largely a mixture of H-group chondrite contamination plus plagioclase cumulates containing intercumulus PLC magma. Since this PLC magma was assumed to contain no Ir, the Ir abundance in a rock was a direct indicator of H-group chondrite contamination. The abundances of Mn,As,Cu,Ga,Ag,Sb,Ge and Zn in the PLC magma (Table 1) have been calculated in this way. Abundances of P,Li,K and Na were obtained from well-established, inter-element correlations in highland rocks, such as $^{La}/_{P}$[5], $^{Li}/_{Zr}$[6], $^{K}/_{La}$[7] and $^{Na}/_{K}$. Estimated abundances of these elements in terrestrial oceanic tholeiites [1] are also provided in Table 1.

We proceeded to compare the calculated abundances of the Set 2 and Set 3 elements in the PLC magma with the observed abundances in terrestrial oceanic tholeiites (Table 1). In making this comparison for each of the elements, we divided the calculated PLC abundances by the terrestrial abundances (Table 1) and plotted these ratios against "condensation temperatures" as a measure of relative volatilities (Fig. 1). The condensation temperatures were those appropriate to the solar nebula, based on a summary [1] of the results from several workers. However, S and Se were not plotted in Fig. 1 since the condensation temperatures of these two elements are extremely sensitive to hydrogen fugacity. We do not consider it firmly established that a solar hydrogen abundance prevailed in the nebulae from which the moon and Earth formed.

The remarkable characteristic in Fig. 1 is that our Set 2 siderophile

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elements display the same general pattern of depletion in the PLC magma (compared to terrestrial basalts) as that shown by the Set 3 lithophile elements. The substantial degree of scatter is only to be expected in view of the simple approach adopted. However, it is clear that the depletions of Set 2 siderophile elements in the PLC magma relative to terrestrial tholeiitic basalts correspond to expectations based largely upon their volatilities, instead of upon their siderophile nature. This relationship suggests that the moon could have been derived from the Earth's mantle accompanied by systematic depletions in the Set 2 siderophile and Set 3 lithophile corresponding roughly to each element's relative volatility. The observed abundances (Table 1) do not seem to be readily explicable in terms of any reasonable cosmochemical fractionations in the solar nebula prior to accretion.

In our model, we have assumed that the composition of the meteoritic contamination in the highlands was similar to H-group chondrites, which possess nearly primordial relative abundances of elements more refractory than Au and moderate to strong depletions of elements more volatile than Au. Although a general model of this kind is suggested by the results of Gros et al. [8], there is no requirement that the actual meteoritic contamination be identical to H-group chondrites. We could equally well have selected a terrestrial (i.e. whole Earth) abundance pattern, which is more strongly depleted in many volatile elements than H-group chondrites. On the other hand, it does not appear that the meteoritic contamination was similar to Cl chondrites [e.g. 8] because there is insufficient Bi and Te (relative to Ir) in the Apollo 16 highlands to support such a component. Since there is a trade-off between the abundance pattern of volatile elements assumed to be contributed by the meteorite component and that calculated in the indigenous lunar component, no unique solution for the volatile element abundances in the PLC magma is possible at present. However, as long as the actual meteoritic component possessed some depletion (relative to Cl chondrites) of elements more volatile than Au, as suggested by Bi and Te, the calculated indigenous abundances of Au,As, Ge and Zn in the Apollo 16 highlands appear to be appreciably greater than those observed in mare basalts. At least two possible causes of these overabundances can be considered. Firstly, the mare basalts may have been derived from a separate, more volatile-depleted chemical system than that associated with the early differentiation event that produced the lunar highlands. Alternatively, the Apollo 16 highlands may have been enriched in some volatile elements as a result of fumarolic activity [9].

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TABLE 1

	PLC MAGMA	OCEANIC THOLEIITES [1]
	SET 1 (Undepleted* Siderophiles)	
W	∿100 ppb	100-150 ppb
Ni	∿200 ppm	200-250 ppm
Co	30 ppm	40 ppm
P	∿280 ppm	570 ppm
Au	∿1 ppb	∿2 ppb
S	700 ppm	900 ppm
Se	180 ppb	170 ppb
	SET 2 (Depleted* Siderophiles)	
As	200 ppb	∿1 ppm
Cu	10 ppm	100 ppm
Ag	4 ppb	30 ppb
Sb	∿2 ppb	29 ppb
Ge	400 ppb	1.5 ppm
	SET 3 (Depleted* Lithophiles)	
Li	6 ppm	14 ppm
Mn	870 ppm	1360 ppm
Ga	5 ppm	20 ppm
Na	3000 ppm	19440 ppm
K	300 ppm	2000 ppm
Zn	11 ppm	100 ppm

*Discussion in the text uses the terms "depleted" and "undepleted" to refer to the relative abundances of elements between the PLC magma and terrestrial oceanic tholeiites.

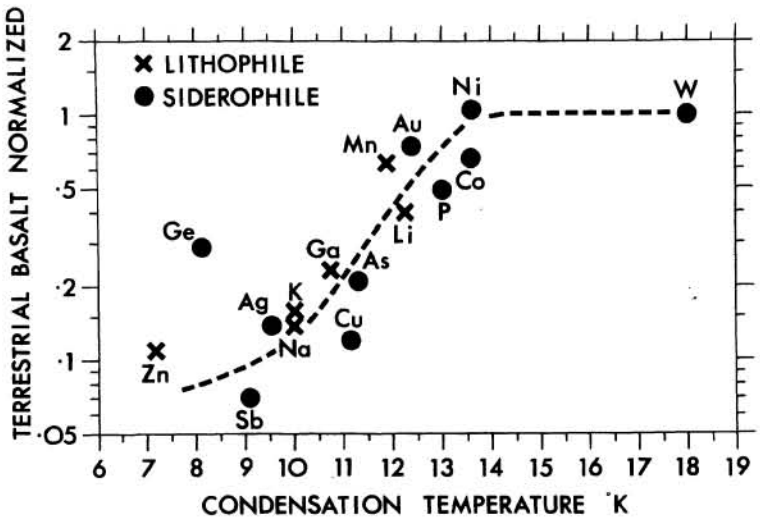

Fig. 1

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