Introduction
The abundance patterns of volatile elements in the earth's mantle and the moon can provide information on the chemical environments and temperatures of accretion of these bodies. Siderophile element abundance patterns, on the other hand, can provide information on the conditions of core formation in the earth, and can be used to test the possibility of a genetic link between the earth's mantle and the moon.

Siderophile and volatile element abundance patterns for the earth's mantle and the moon were obtained from primitive ocean floor basalts and primitive low-Ti mare basalts respectively, supplemented by data from terrestrial ultramafics. Low-Ti mare basalts were selected because they are believed to carry the most direct chemical "memory" of the primordial lunar interior; high-Ti basalts were excluded because of their more complex petrogenetic history [I].

Since both the lunar and terrestrial basalt suites are believed to have formed by substantial (~15%) degrees of partial melting of their respective source regions [2], trace-element partition behaviour is readily predicted. For both compatible and incompatible elements (Kp melt/residuum < 1 and > 1 respectively), abundance ratios for moon/earth's mantle were obtained from lunar/terrestrial basalt ratios. For elements with Kp < 1, experimentally-determined partition behaviour was taken into account in order to obtain lunar/terrestrial ratios. Uranium abundances in earth's mantle and moon are believed to be quite similar [3]. In order to avoid the problems arising from the prior depletion of some LIL elements (e.g. K, Rb, Th) in the source regions of ocean floor basalts [4] terrestrial/lunar comparisons of these elements were made on a U-normalized basis with terrestrial ratios obtained from sources such as average crustal abundances.

Siderophile element abundance patterns in the earth
The depletions of siderophile elements in the earth's mantle relative to chondritic (=solar nebula) abundances reflects both volatility and segregation of these elements into the core. However the magnitudes of these depletions are not consistent simply with low-pressure equilibrium between silicates and a metal phase subsequently segregated into the core - many elements eg. Ni, Co, Cu, Au, Re are "overabundant" in the earth's mantle by factors of 10 to 1000 [5]. A plausible explanation for the overabundances of certain elements which show remarkably low dispersions in mantle rocks (e.g. Ni, Co), is that metal-silicate partition behaviour in the deep mantle differs from that observed at low pressures. The low dispersions are consistent with high-pressure high-temperature equilibrium followed by convective redistribution. However the overabundances of elements such as Ir, Au, Re, Os, Pt with extremely wide dispersions, are better explained by inhomogeneous physical mixing of a low-temperature condensate containing the primordial abundances of these elements,
with mantle material previously equilibrated with metal. The siderophile
element abundance patterns in the earth's mantle therefore reflect the
operation of processes unique to the earth including (1) pressure
effects on metal-silicate equilibria and, (2) physical mixing of a
low-temperature condensate with mantle material under conditions where
equilibrium with metal was not achieved.

Siderophile element abundance patterns in the moon

Compared to the earth's mantle, the moon is not inherently depleted in
all siderophile elements. Substantial depletions (factors of 5 to 500) are
exhibited only by siderophile elements which are also volatile e.g. Cu, Ga,
Ge, As, Pd, Ag, Sb and Au. Several siderophile elements of low to inter-
mediate volatility e.g. Fe, Ni, Co, W, Os, Ir, P, and also S and Se, display
similar relative abundances in the earth's mantle and the moon (within a
factor of 60%). These similarities are of profound genetic significance,
showing that the source region of low-Ti mare basalts, in common with the
earth's mantle, was not in equilibrium with metallic iron. Likewise the high
Ni contents (up to 400 ppm) of liquidus olivines in primitive low-Ti basalts
[6] imply that metallic iron was not present.

The factors responsible for the unique siderophile element signature of
the earth's mantle cannot have operated in the case of the moon, since the
lunar core (if any) is very small. Moreover the pressure field at the
centre of the moon reaches only 47 kilobars as compared to 3.6 megabars for
the earth. The remarkable similarity between lunar and terrestrial mantle
involatile, siderophile element abundances strongly suggests that the moon
was derived from the earth after the earth's core had segregated.

Volatile element abundance patterns in the earth

By comparing the volatile element abundance patterns in the moon with
those in the earth's mantle and with chondritic (=solar nebula) abundances,
it is possible to characterize the thermal and chemical environment during
accretion. The degree of depletion of volatile elements in the earth's
mantle correlates well with the nebula condensation sequence, leaving little
doubt that terrestrial depletions are primarily a consequence of selective
condensation/volatilization processes. The depletions of some elements (e.g.
Cu, Ag, S, Se, Ge, Cd, Bi, Pb, Tl) are enhanced by their siderophile nature
which has resulted in preferential entry into the earth's core. The abundance
of sulphur (and Se) in the bulk earth (mantle plus core) is anomalously high,
since sulphur is significantly less depleted than elements of lower volatility
e.g. alkali metals, Zn. The conditions under which this could happen are
extremely restrictive and imply that the earth accreted in an environment in
which, relative to the solar nebula, hydrogen pressures were much lower so
that the formation of the volatile species H2S and H2Se was inhibited.

Volatile element abundance patterns in the moon

The large depletions of volatile elements in the moon relative to the
solar nebula demonstrate that volatility is a controlling factor, however the
depletion patterns cannot be explained in terms of the nebula condensation
sequence, nor in terms of fractionation models based on this sequence. For
example, a group of elements which should behave coherently [7] and should
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show a similar degree of depletion during solar nebula condensation (As, Cu, F, Ag, Se, S, Zn, Ge) in fact show an enormous range of depletions in the moon, (0.04 for Ga to 0.00006 for Ge). Secondly, many of the lunar depletion patterns do not correlate directly with the nebula condensation sequence. Ge, which in the solar nebula should condense before Zn, S, Cd, Pb, In, Bi, Ti, and In, is depleted by up to 100-fold in the moon when compared to these elements. Thirdly, the condensation of As, Sb and Ge in the solar nebula is strongly influenced by compound-formation with metallic iron [7]. The abnormally large depletions of these elements in the moon thus suggest condensation in an environment where metallic iron was absent, and which was very different from the solar nebula. Finally, the relatively high abundances of S (and Se) in the moon relative to elements of similar nebula volatility indicate low hydrogen pressures during accretion, as in the case of the earth.

The above features of the volatile element abundance patterns for the moon imply that the moon was not formed from components which themselves had condensed directly from the solar nebula. For these reasons, current versions of the capture and binary planet hypotheses of lunar origin, which maintain that the moon formed independently by accretion in the solar nebula, can be rejected. In an earlier section it was concluded that the similarities in the abundances of many siderophile elements between the earth's mantle and the moon implied that the moon had been derived from the earth's mantle subsequent to core formation. The drastic depletion of many volatile elements in the moon compared to the earth implies that the separation of material from the earth's mantle to form the moon occurred at very high temperatures. Depletions of this magnitude are best explained by the hypothesis that material from the earth's mantle was totally evaporated, and then selectively recondensed, whilst the more volatile components were lost. The moon then formed in earth orbit by accretion from this volatile-depleted, mantle-derived condensate.

References