LOSS OF VOLATILE ELEMENTS DURING IMPACT EVENTS IN RELATION TO LUNAR
COMPOSITION AND ORIGIN

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The lunar composition is characterised by a massive depletion in volatile elements [1] but these show some marked differences in detail. Thus the moderately volatile elements, such as the alkali elements K and Rb, which condense in the temperature range 800-1200 K at 10^-3 atm. are depleted, relative to CI abundances [2], by about one order of magnitude. The highly volatile elements (eg: Bi, Ti, Cd, Br, Se, Te, In) which condense below about 800 K at 10^-3 atm., in contrast are depleted by factors of about two hundred relative to CI abundances.

Although the Earth is also depleted in volatile elements relative to CI abundances, the depletion is much less, typically by factors of five times for the alkalies to about 50 for the very volatile elements. Venus and Mars seem to be similar to the Earth in this respect, if the broad similarity in K/U ratios is used as a guide to their overall depletion in volatile elements relative to CI. If the SNC meteorites are representative of Mars [3] then that planet may have about twice the volatile inventory of the Earth (ie; K/U ratios of 2 x 10^4 compared to the terrestrial value of 10^3).

This planetary depletion in volatile elements thus appears to be endemic in the inner solar system (there is no reason to suppose that Mercury is volatile-rich). This loss is presumably related to an overall loss both of volatile elements and the noble gases from the inner nebula due to early intense solar activity as the sun settled onto the main sequence [4]. In contrast to the inner planets, the moon thus shows a much more extreme depletion of volatile elements (including a total absence of both indigenous noble gases and water), and this is a critical observation which points toward a singular mode of origin for the Earth's satellite.

What processes might account for such a massive loss of volatile elements? If the moon was assembled from any set of precursor planetesimals typical of those from which the inner planets were formed, then it should not show such extreme depletion so that two stages of volatile depletion from CI abundances seem to be called for. Among the various competing hypotheses for lunar origin, only those which incorporate a mechanism for high temperature processing of the proto-lunar material are capable of explaining the "bone-dry" and refractory nature of the moon [5].

The Mars-sized impactor model [6,7] postulates an extremely energetic mode of formation for the moon, predicting high temperatures, including vaporisation, in some variants [7]. Extrapolation from laboratory-based data to such conditions is difficult, so that it is useful to seek other natural examples where silicate materials have been subjected to extreme temperature conditions for brief periods of time.

One much studied smaller scale analogue is the production of natural glasses, such as impactites and tektites, which have resulted from melting of silicate country rock during the impact on the Earth, of asteroids, meteorites or comets. Impactites possess the general advantage that the country rock is generally available for comparison, while for tektites, the parental material can usually be only indirectly identified. This situation is simplified by the rather close similarity between the composition of tektites and that of upper crustal sedimentary material (eg; loess, subgreywacke, arkose) of wide geographic
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These sediments are sufficiently close in composition to the various classes of tektites to enable useful comparisons to be made [8,9].

Comparative studies have been made for four classes of impactites (Henbury impact glass, zhamanshinites, Muong-Nong glasses and Darwin Glass) and several groups of tektites (australites, javanites, indochinites, philippinites, irghizites) [9-14].

**Impact Glasses:** There is a particularly close correspondence between the composition of the parental Henbury sediments and the impact glasses derived from them [9,14]. This similarity extends to the impactites from Zhamanshin, which are of analogous composition [9]. Likewise the Darwin Glass composition matches that of typical arkosic sandstones. There is no depletion of such volatile elements as Cs, Tl, Pb, Sn, Bi, Cu or Ga, compared to the country rocks. Muong-Nong glasses also are undepleted [11,12,13]. The retention of these elements is attributed to the much lower temperatures experienced during the formation of impact glasses compared to the much more energetic tektite forming events.

**Tektites:** In contrast to the impactites, the tektites show depletion of the volatile elements such as Cs, Tl, Pb, Bi, and Cu [9,14]. This depletion is unlikely to have been an inherent feature of the chemistry of the parental material, since the abundances of the other elements bear a close similarity to those of the impactites. Close analogies exist between the australites and Henbury impact glasses, and between the silica-rich irghizites and zhamanshinite [9]. The latter example is particularly significant, since both glasses formed in the same event. Clearly the irghizites experienced higher temperatures.

It is concluded that smaller impact events, although producing impact glasses, do not cause loss of such volatile elements as Cs, Pb and Bi. In contrast, the highly energetic processes which produce the tektite strewn fields, do cause significant depletion of such elements from silicate parental material, even on the short time scales of such events. Tektite-producing impacts thus produce analogous volatile element depletions to those observed in lunar compositions, so providing additional support for the giant impactor hypothesis of lunar origin, though from a somewhat ironic source.