ON THE DIFFERENTIATION OF THE TERRESTRIAL PLANETS
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There is a widely-held view that the geochemical and geophysical properties of the Moon may best be understood in the context of an early global differentiation event, often referred to as the "magma ocean". The heating mechanism or mechanisms responsible for melting the Moon are unknown. However, it is possible to examine the effects on other terrestrial planets of various possible combinations of heat sources which might have been responsible for melting the moon.

Hostetler and Drake (1980) considered as heat sources various combinations of short-lived radioactivities, enhanced solar luminosity, electrical induction, accretion, adiabatic compression of nebular gasses, and tides. These potential heat sources were linked to an early solar system chronology. Hostetler and Drake concluded that, if the terrestrial planets achieved their present masses in less than approximately $10^6$ years, all would have undergone global magma ocean events. However, if the planets took in excess of $10^6$ years to accrete, the results may be summarized as follows:

(i) Unless the Moon received greater than 60-70% of its thermal input for tidal interactions with Earth, any combination of adiabatic compression, induction, and accretion sufficient to produce the lunar magma ocean would have produced a Mercurian magma ocean.

(ii) Unless the Moon received greater than 80% of its thermal input from tidal heating and/or induction, any combination of adiabatic compression and accretion sufficient to produce the lunar magma ocean would have produced a Venusian magma ocean.

(iii) Unless the Moon received greater than 80-90% of its thermal input from induction, any combination of tidal heating, accretion, and adiabatic compression sufficient to produce the lunar magma ocean would have produced a Terrestrial magma ocean.

(iv) Unless the Moon received greater than 50-60% of its thermal input from induction and/or tidal heating, any combination of accretion and adiabatic compression sufficient to produce the lunar magma ocean would have produced a Martian magma ocean.

It is, in principle, possible to constrain the primary (magma ocean) and secondary episodic differentiation events on the terrestrial planets by examining rare gas abundances in planetary atmospheres. For example, $^{40}$Ar is produced by decay
of $^{40}K$ and, thus, may be used to investigate secondary episodic outgassing of planets. In contrast, $^{38}Ar$ is stable and will be outgassed in both primary and secondary events. In this case, interpretation is complicated somewhat by uncertainties in the initial abundances of rare gases accreted to the planets (see Pollack and Black, 1979; Hostetler, 1981).

Early reports (Pollack and Black, 1979) of atmospheric abundances from Pioneer-Venus suggested that Venus was depleted in $^{40}Ar$ ($8 \times 10^{-10} - 7 \times 10^{-9} \text{ g/g}$) relative to Earth ($1.1 \times 10^{-8} \text{ g/g}$), the lower reported values approaching those of Mars ($5.4 \times 10^{-10} \text{ g/g}$). Clearly Mars has undergone substantially less outgassing than Earth. These data led Drake and Hostetler (1980) to conclude that Venus had also undergone substantially less secondary outgassing than Earth. If one adopts a fraction of secondary outgassing for the Earth ($f_2$) of 0.5 following the work of O'Nions et al. (1979), the $^{40}Ar$ abundance range reported for Venus corresponds to $f_2 = 0.04-0.32$, if the amount of $^{40}K$ in Venus is the same as in Earth ($40Ar \propto f_2 \cdot 40K$). The paradox arose that if less $^{40}K$ were assumed for Venus, a larger value of $f_2$ is calculated following the proportionality relationship listed above, i.e., smaller quantities of long-lived radioactive heat sources lead to a greater efficiency of secondary episodic outgassing. This paradox led Drake and Hostetler (1980) to propose significant heat contributions to episodic secondary outgassing from non-long-lived radioactive heat sources for Earth but not for Venus, with speculations focussing on possible fossil contributions from tidal heating and/or core formation.

Unfortunately early reports of $^{40}Ar$ abundances in the Venus atmosphere were in error, and recent revisions (Hoffman et al., 1981) indicate that the $^{40}Ar$ abundance for Venus is approximately one third of that for the Earth's atmosphere. Although the conclusions of Drake and Hostetler (1980) cannot be excluded, a simpler explanation now presents itself. Venus should have experienced a magma ocean event comparable to that of the Earth (Hostetler and Drake, 1980), suggesting similar efficiencies of primary outgassing ($f_1$) for both planets, unless tidal heating was important for the early Earth-Moon system. Soviet Venera gamma ray analyses of the Venus surface suggest Earth-like $K$ abundances in surface rocks. Thus Venus may have essentially the same $K$ abundances as Earth, but have experienced less efficient secondary outgassing ($f_2$) than Earth. The absence of evidence for plate tectonics is consistent with this view. Less efficient secondary outgassing may simply be a consequence of Venus' smaller radius, hence higher surface/volume ratio.
DIFFERENTIATION . . . PLANETS

DRAKE and HOSTETLER

REFERENCES


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