MODELING SODIUM ABUNDANCE VARIATIONS IN THE LUNAR CRUST: A LIKELY PROXY OF PAST SOLAR SYSTEM HISTORY AND A POTENTIAL GUIDE TO CLOSE-IN ROCKY EXOPLANETS.

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Introduction: While the Moon and Earth are generally similar in terms of composition, there exist variations in the abundance of certain elements among the two bodies. These differences are a likely consequence of differing physical evolution of the two bodies over the solar system's history. We describe how our past and current modeling efforts indicate that a significant fraction of the initial sodium budget of the Moon may have been depleted and transported from the lunar surface since the Moon's formation. Using profiles of sodium abundances from lunar crustal samples may thus serve as a powerful tool towards exploring conditions on the Moon's surface throughout solar system history. Conditions on the Moon immediately after formation may still be recorded in the lunar crust and may provide a window towards interpreting observations from some of the first rocky exoplanets that will be most amenable to characterization. Potential spatial variation of sodium in the lunar crust may be a relevant consideration for future sample return efforts.

Sodium Depletion in the Lunar Crust: Lunar samples indicate the Earth and the Moon are generally very similar in composition, but that there exist significant depletions in elements that possess condensation temperatures less than 1300 K (at a pressure of 10^{-4} bar)[1]. Sodium appears to be approximately five times more abundant in the Bulk Silicate Earth versus the Bulk Silicate Moon, with significant variation depending on the particular lunar sample chosen. [2] Some of these abundance variations have been attributed to incomplete accretion during the formation of the Moon immediately after a hypothesized giant impact on the Earth. [2] However, processes operating after accretion of the Moon may also have influenced sodium abundance and spatial variation on the Moon.

Post-Formation Depletion and Transport Mechanisms: We examine two mechanisms that may have influenced sodium abundances:

A Primordial Lunar Atmosphere. Given a canonical Moon formation hypothesis where the Moon accreted quickly from a disk created when a planetary sized impactor hit the Earth, the Moon may have possessed a short-lived largely hemispheric metal dominated atmosphere immediately after it tidally locked to the Earth. Sodium would have been a significant (and potentially dominant) constituent of this atmosphere. Such an atmosphere was characterized by moderate pressures, high atmospheric temperatures, strong supersonic winds and large atmospheric scale heights. [3] Estimates of atmospheric (and consequently sodium) escape from such an atmosphere range from 5-25% of the initial sodium content of the global lunar magma ocean. [3] Additionally, sodium would have been transported rapidly to regions of the Moon near or just beyond its' terminator with respect to the Earth. This transport would have occurred right up to and during the beginning of lid formation and may have produced sodium depletions from sub-Earth zones while producing significant sodium abundance enhancements on rockbergs [4] that were advected towards the far side.

Effects of Past Solar Activity. Sodium may also have been depleted due to solar activity in the past. Recent research based on Kepler observations of solar analogues at different stages in their evolution indicate the Sun may have experienced an enhanced period of flare and CME activity earlier in its history. [5] This enhanced CME activity may have resulted in a frequency of geoeffective high energy CMEs on the Earth-Moon system of >1/day in the first 500 million years of the Solar Systems history. Using a previously developed exosphere generation model that includes the effect of an incident CME [6], we are able to estimate the potential loss of sodium from the regolith due to solar wind and CME effects. Depending on the choice of composition (LPUM versus TWM), even with a conservative model of sputtering yields, this enhanced solar activity may explain anywhere from 10-100% of the observed sodium depletion. Additional modeling considering other physical mechanisms that may effect sodium abundance and spatial variations should be a focus of future work. Eventually, connecting vertical profiles of sodium abundances in lunar samples to physical mechanisms may be a potential means of exploring lunar surface history.

References:

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