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Cosmochemically Earth-like exoplanets

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Abstract

Discoveries of rocky worlds around other stars have inspired diverse and disparate geophysical models of their plausible structures and tectonic regimes [1]. These models are severely hampered, however, by inexact assumptions about key geophysical parameters such as long-lived radiogenic heat production (^{235,238}U, ^{232}Th, ^{40}K) and inventories of rock-forming elements (e.g. Si, Al, Fe, Ca, Na, Mg). Host stars of planets ought to reflect the overall compositions of planetary systems [2]: to date, the only con-firmed connection between stellar host abundances and planets is the presence of Jupiter-mass worlds around stars with enriched [Fe/H] content [e.g. 3]. Abundances of particular elements within the planet govern mantle processes, and thus the nature of its crust, composition of atmosphere and retention of a hydrosphere. Without plate tectonics dictated by mantle rhealogy (internal heat, mineralogy, water content) a carbon cycle is unlikely. To better under-stand exoplanets, we must understand how differences in stellar host compositions would be reflected in the evolution of exoplanets. Galactic Chemical Evolution (GCE) models of star (and planet) age and composition yield different effects on geodynamical regimes.

Earth-like exoplanetary mantles

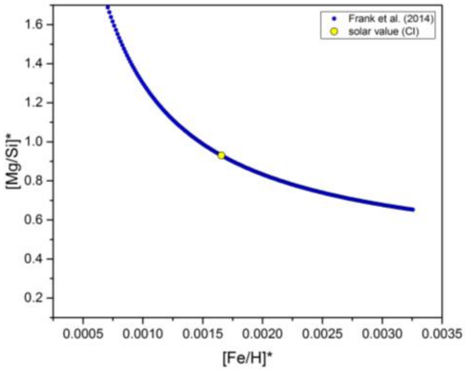

Figure 1. Mass fractions of Mg:Si vs. Fe:H in the analytical GCE model of [4]. Solar model value shown.

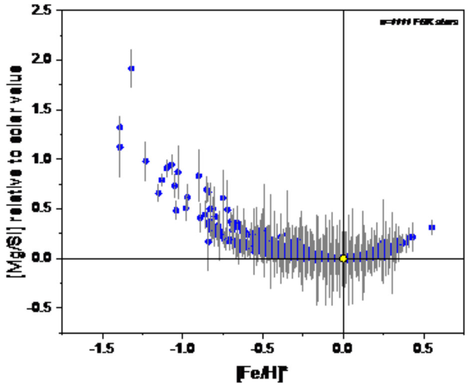

Figure 2. Correlated [Mg/Si] vs. [Fe/H] in dex units normalized to solar values for 1111 FGK stars [8].

Recent [4] GCE codes: (1) improve models for the evolution of radiogenic heating in rocky exoplanets and (2) assess the geophysical effects of different rock-forming element inventories (e.g. Mg/Si; Figure 1) emphasizing factors that affect geodynamic regimes (e.g. mantle properties, heat production, crust type). Key processes related to the geodynamics of "Earth-like" rocky planets begin with mantle com-positions which result in different geodynamical states [5,6]. To summarize: (i) Earth's Primitive Mantle [Mg/Si] is ~1.03 (CI=0.93); (ii) The dominant upper mantle (UM) phase of that composition is olivine $(Mg,Fe)_2(SiO_4)$ for which no lattice site can accommodate Fe3+; (iii) If Earth had inherited a slightly lower [Mg/Si] (e.g. 0.8), pyroxene ($(XY(Si,Al)_2O_6$, where X represents divalent Ca, Mg and Fe, and Y represents trivalent Cr, Al, Fe) would dominate. Pyroxene takes up Fe^{3+} into its structure and with substitutions maintains low activity of Fe^{3+} and a very low oxygen fugacity; (iv) Owing to (ii), the Fe^{3+} present in the Earth's UM goes into spinel ($(Mg,Fe)Al_2O_4$) such that there is a modal phase imposing a high oxygen fugacity (~FMQ) on gases in equilibrium with rock; (v) Consequently, Earth's UM always degassed a relatively oxidized form of carbon (CO-CO_2) rather than an alternative mantle which would degas CH_4-CO [e.g. 7]. In exoplanetary systems, we expect that subtle changes such as in [Mg/Si] from different stellar sources or ages make the difference between a CH_4 vs. CO_2 atmosphere and a fluid, convecting (pure olivine) interior vs. a stiff, non-convecting (pure pyroxene), mantle (Figure 2).

Acknowledgements

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