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Earth's Early Evolution: A felsic crustal composition during the Hadean

JORDAN FALTYS[1], MATTHEW M. WIELICKI[2] AND JONATHAN FRAME[2]

[1]University of Alabama-Department of Geological Sciences
[2]University of Alabama

Presenting Author: Jfaltys@crimson.ua.edu

The National Research Council identified Exploring Earth's "Dark Ages" (the first 500 Myr) as one of the fundamental questions driving the geological and planetary sciences. Due to Earth's constant resurfacing, any early crust presence has inevitably been recycled during the Hadean, leaving no trace of information regarding its composition or abundance. Although modern continental crust formation tends to be associated with plate tectonics, a different mechanism is required to produce an evolved crust in the absence of a plate tectonic regime. One such possible mechanism on early Earth is the processing of the surface through impact melting. Utilizing the Sudbury Igneous Complex geochemistry, we notice a clear evolution throughout the fractionated impact melt sheet in wt.% SiO_2 and Sr and Nd isotopic ratios. Using Sudbury as a proxy of how impactors process the early crust, we model multiple impact events on a primitive mantle to illustrate how impacts can evolve crustal compositions early in Earth's history before the likely onset of plate tectonics. The IMPaCS, or Impact Melt Partitioning and Compositional Stratification, equation (Eq. 1) defines the evolution of an impact melt as a function of impactor diameter and target composition. From applying a fractionation factor identified from the Sudbury impact and primitive mantle wt.% SiO_2 and initial $^{87}Sr/^{86}Sr$ ratio, we find that it is possible to create average continental crustal compositions of 60 wt.% SiO_2, and $^{87}Sr/^{86}Sr$ of 0.72 after just a few impacts (Fig. 1). This model illustrates the creation of a relatively thin (~few km's) layer of evolved crust, but not the crystallization of Hadean zircon, which suggest deeper depths of formation. Employing a dynamic geospatial model of IMPaCS, using the size-frequency distribution of impacts scaled from the lunar surface, we estimate the volume and abundance of this enriched crust on Earth's surface during the Hadean to determine how rapidly it evolved. Our results suggest the inevitable presence of evolved crustal compositions near Earth's surface early in the Hadean and possibly a contributing factor into the eventual onset of plate tectonics and possibly providing the ingredients necessary for the origin of life.

$$wt.\%_{target}^{SiO2} = \sum_{l=1}^{n} \left(\frac{d_l}{M_i}\right) wt.\%_l^{SiO2}$$

$$wt.\%_{target}^{SiO2} = \left(\frac{d_{upper}}{M_i} \times wt.\%_{upper}^{SiO2}\right) + \left(\frac{d_{lower}}{M_i} \times wt.\%_{lower}^{SiO2}\right)$$

$$wt.\%_{upper}^{SiO2} = \frac{wt.\%_{target}^{SiO2}}{1 - I_f} \quad \text{Where,} \quad I_f = 1 - \frac{wt.\%_{target}^{SiO2}}{wt.\%_{upper}^{SiO2}}$$

$$wt.\%_{lower}^{SiO2} = \frac{wt.\%_{target}^{SiO2} - \left(\frac{d_{upper}}{M_i} \times wt.\%_{upper}^{SiO2}\right)}{\frac{d_{lower}}{M_i}}$$

Equation 1*:* **IMPaCS:** *wt.%* = Concentration, SiO_2 = wt.% SiO_2, *n* = number of layers, *l* = layer number from top to bottom, *d* = depth of layer, M_i = Depth of impact melt, *upper* = upper portion of the impact melt, *lower* = lower portion of the impact melt, I_f = impact fractionation factor, where I_f is a function of projectile diameter, velocity, angle of impact, target density, projectile density, and time of crystallization.

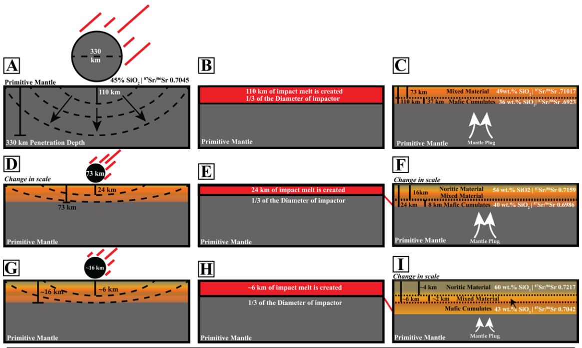

Figure 1: A step-by-step box model illustrating how a series of impacts on the same area of Earth can evolve the surface. Red lines indicate change in scale. **[A]** Initial primitive mantle composition at surface of 45 wt% SiO_2 and $^{87}Sr/^{86}Sr$ isotopic ratio of 0.7045. An initial impactor with a diameter of 330 km (scaled 1/10 size of Utopia crater, Mars) hits the surface with a penetration depth equal to its diameter. **[B]** The resulting surface from the previous impactor, creating 110 km of impact melt. **[C]** Final crystallized surface from initial impact. The upper (2/3) portion has evolved to 49 wt.% SiO_2 and Sr isotopic ratio of 0.7102. **[D]** After fully crystallizing, a second impactor hits the same surface scaled as the diameter of the upper portion of [C]. **[E]** The 73 km impactor creates 24 km of impact melt. **[F]** The resulting surface from [D], the upper portion has evolved to 54 wt.% SiO_2 and a Sr isotopic ratio of 0.7159. **[G - I]** A third impactor hits the same surface of [F] creating 6 km of impact melt. This results in a thin layer of compositionally evolved crust of 60% SiO_2 and a sr isotopic ratio of 0.7217