UPDATED STATUS OF THE IMPACT – ORIGIN OF LIFE HYPOTHESIS. David A. Kring, Lunar and Planetary Institute, USRA, 3600 Bay Area Blvd., Houston TX 77058 (kring@lpi.usra.edu).

Introduction: In our initial studies of the Chicxulub impact crater (e.g., [1]), we found evidence of impact-generated hydrothermal activity. Soon thereafter similar alteration was described by other investigators, notably Naumov [2-4], in other impact craters. Hydrothermal activity seemed to be a widespread consequence of impact heating of hydrous planetary crust.

It was also understood from analyses of Apollo samples, that the Earth, at the dawn of life, was being pummeled by impacting asteroids and comets. Some of the largest of those impacts should have vaporized seas [5], making conditions untenable for life at the surface. Based on observations at Chicxulub [1], I proposed [6-8] those same impact events were producing vast subsurface hydrothermal systems that were perfect crucibles for pre-biotic chemistry and habitats for the early evolution of life (the impact – origin of life hypothesis). The end of the period of heavy bombardment coincided with the earliest isotopic evidence of life [9], although it was uncertain (and remains uncertain) whether life truly emerged at that time or was of a type capable of surviving the bombardment [10,11]. Analyses of ribosomal RNA made in the same decade indicated the earliest organisms on Earth were thermophilic and hyperthermophilic [12-14]. It seemed plausible life originated in an impact crater.

Two Decades of Investigation: There are two paths to take when testing that hypothesis. One is a biological path, exploring evolutionary roots. The idea of an community of thermophiles and hyperthermophiles is still favored by some, but challenged by others, often on grounds of horizontal gene transfer. It is still unsettled science. The other path is to examine the impact processes occurring during those first billion years of Solar System history and their effects on environmental conditions. That is the path explored here.

Magnitude and duration of impact bombardment. Analyses of Apollo samples suggested the final third of lunar basins were produced c. 3.9-4.0 Ga [15,16]. Analyses of additional Apollo samples and, importantly, lunar meteorites representing a larger geographic region, support a large number of impacts at roughly that time (e.g., [17-19]), although we still debate precise ages (e.g., [20]). A tentative age for the oldest and largest basin on the Moon, the South Pole-Aitken basin, is c. 4.35 Ga [21]. If accurate, then an intense bombardment affected the Moon for ~400 Myr. The flux was probably not constant. Indeed, SPA may have been produced from a different population of impactors, so the magnitude and duration of any spike in the impact rate remains uncertain. Nonetheless, it is clear that the neighboring Hadean Earth was being resurfaced by an even larger quantity of impactors with larger sizes than the Moon (e.g., [21-24]).

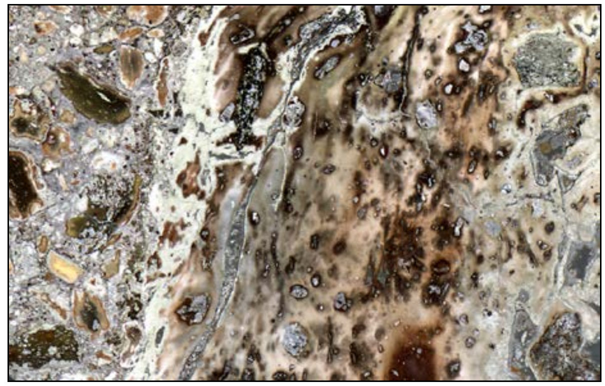

Figure 1. *Hydrothermally-altered impactite in the Yaxcopoil-1 core sample YAX-1_857.65m of the Chicxulub impact crater [46]. Field of view is 3.3 cm wide.*

Earth on Moon? One wonders about the crust of the Hadean Earth being affected by impacts: was it ultramafic (e.g., reflective of komatiitic eruption temperatures) or granitic (e.g., as inferred from Hadean zircon chemistry). A fragment of a Hadean rock has tentatively been identified in an Apollo 14 sample [25] that not only provides additional evidence of a granitic crustal component, but also is a product of the intense bombardment occurring c. 4 Ga.

Asteroids vs. Comets. Geological, mineralogical, and geochemical fingerprints imply ≥80% of the impactors were asteroids, not comets ([26] and references therein). Impactors delivered significant quantities of biogenic elements, but the bulk of Earth's water was delivered during an earlier phase of accretion.

Extent of hydrothermal systems. We have had two opportunities to augment our initial investigations of the Chicxulub impact crater. In 2001-2002, we recovered hydrothermally-altered core from a second site (e.g., [27,28]) and in 2016 hydrothermally-altered core from a third site (e.g., [29]), the latter of which probed the peak ring in a specific quest to test our model of impact-generated hydrothermal activity [30]. The results demonstrate hydrothermal activity affected a large volume of the crust, essentially the entire diameter of the crater. Hydrothermal alteration at other impact sites continued to accumulate, too (e.g., [31-33]).

Lifetime of a hydrothermal system. Models indicate the systems are long-lived [30,34], allowing for evolutionary processes to occur within a crater and migration of biologic material to adjacent impact sites.

Nature of the crust, mineral assemblages, and chemical reactions providing energy. Because the bulk Earth was hotter in the Hadean, the crust may have been dominated by ultramafic to mafic lithologies. In that case, impact-generated hydrothermal activity would produce serpentinization reactions, which are a notable energy source for organisms (e.g., [35]). However, evidence of granitic crustal components has been growing. The energy source for organisms in that case is less clear.

Application to Mars and elsewhere. It became evident (e.g., [36-38]) that the lunar impact cataclysm was an inner Solar System event that affected all terrestrial planetary surfaces. Because impact-generated hydrothermal systems are possible in any hydrous planetary crust, models for systems on Mars have been developed (e.g., [39-44]). Those are obvious targets for astrobiological investigation.

Conclusions: Several features of the impact – origin of life hypothesis have been investigated since it was first proposed. A period of bombardment is confirmed; impactors are dominated by asteroids; the impacts resurfaced the Earth and generated geographically broad and long-lived hydrothermal systems. More remains to be done. Chicxulub core samples should be probed to extract additional clues about the thermal and chemical evolution of large hydrothermal systems. Theoretical or experimental studies of potential energy sources for organisms in granitic crust during the Hadean are needed. Samples from specific basins on the Moon, such as the Schrödinger, South Pole-Aitken, and Orientale basins, are needed to clarify impact chronology. Finally, surveys of lunar regolith samples for fragments of Hadean Earth should continue. If sedimentary and fossiliferous samples can be located, they would provide a direct record of the early evolution of life on Earth.

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