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# Impacts and Life: New Methods for Identifying Ancient Terrestrial Cratering Events

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It was not until decades after Shoemaker (1960) first documented a terrestrial impact structure that the relationship between such impacts and mass extinctions was clearly hypothesized (Alvarez et al., 1980). Although still controversial, this new view altered the paradigm for critical transitions in the evolution of terrestrial life. The K-Pg (Cretaceous - Paleogene) extinction event, caused by a ~10 km impactor on the Yucatan peninsula (Hildebrand et al., 1991), exterminated the dinosaurs paving the way for the diversification of mammals. Although the global effects of impacts on the terrestrial biosphere can be dramatic, their role in the early evolution of life remains poorly understood. The bombardment history of our planet has major implications for Earth's atmosphere, habitability, near surface conditions, and the delivery of volatiles and the building blocks of life. However, finding terrestrial evidence of impacts is hindered by the constant resurfacing of the planet due to weathering and erosion, essentially precluding using the contemporary terrestrial surface as a record of impact rates. Evidence of the impact flux on the Earth-Moon system has largely been based on interpretations of reset 40Ar-39Ar ages of lunar samples leading to the hypothesis that the inner planets experienced a spike in bolide flux from ~3.8-4.0 Ga – a period known as the Late Heavy Bombardment (LHB; Tera et al., 1974) – which appears to coincide with the earliest evidence of life. The earliest evidence for life on Earth is in the form of carbon isotopes from 3.8 Ga rocks from Greenland (Mojzsis et al., 1996) with the first stromatolite fossils identified in 3.5 Ga rocks from Western Australia (Walter et al., 1980). While many have argued that large impacts would frustrate the emergence of life (Maher and Stevenson, 1988), Abramov and Mojzsis (2009) suggest that LHB- scale impacts might actually increase habitats of thermophilic organisms, seemingly the root of the tree of life (Pace, 1997). With a sparse Precambrian rock record and no >4 Ga rocks, conditions on the early Earth relevant to the evolution of ancient life forms, particularly the rate of impacts, is essentially unknown. Most interpretations of lunar 40Ar-39Ar ages are problematic due to the presence of relic clasts, incomplete argon outgassing, diffusive modification during shock and heating, exposure to solar wind and cosmic rays, and misinterpretations of age spectra (Ferenandes et al., 2013; Harrison and Lovera, 2013). Thus the development of new approaches to identifying impact signatures is urgently warranted. Although Earth has lost the vast majority of its impact features, the few preserved large (ca. 200 km) craters formed over the past 2 Ga permit geochemical investigations into the physical conditions (i.e., shock pressure, thermal, hydrologic, etc.) experienced during bombardment. Our group has developed methods, primarily from analysis by Secondary Ion Mass Spectrometry (SIMS) of the mineral zircon (ZrSiO4), to investigate the physical conditions experienced during impact cratering as well as establishing the timing of impacts in the Archean and Hadean. With regard to the former, SIMS analysis of zircon from the five of the largest terrestrial impact craters (Vredefort and Morokweng, South Africa; Sudbury and Manicouagan, Canada; Popigai, Russia; Wielicki et al., 2012) has provided a large database with which to compare terrestrial and extraterrestrial zircons to constrain their origin and provides the foundation for using zircon as a probe of planetary impact history. Direct comparison of impact-formed zircon and Hadean terrestrial zircon from Western Australia yields a ~100° C greater Ti-in-zircon crystallization temperature of impact-produced grains suggesting that impacts were not a dominant source of the terrestrial population. Zircon sieve textures identified in lunar meteorite SaU 169 as poikilitic impact melt zircon formed during equilibrium crystallization of the impact melt and used to constrain the age of Imbrium (Liu et al., 2012) have been identified in Vredefort impactites and shown to be inherited from the target rock and thus should not be used to identify impact age. This example

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underscores the necessity to have proven criteria with which to identify grains that accurately date the impact event and are not inherited from the target. Accurately identifying impacts within the geologic record is essential prior to investigating coincident transitions in the evolution of life and constraining the role of impacts on such transitions.

**References**

Abramov, O., Mojzsis, S.J., 2009. Microbial habitability of the Hadean Earth during the late heavy bombardment. *Nature*, 459: 419–422.

Alvarez, L.W., Alvarez, W., Asaro, F., Michel, H.V., 1980. Extraterrestrial Cause for the Cretaceous-Tertiary Extinction. *Science*, 208: 1095-1108.

Fernandes, V.A., Fritz, J., Weiss, B.P., Garrick-Bethell, I., Shuster, D.L., 2013. The bombardment history of the Moon as recorded by $^{40}$Ar-$^{39}$Ar chronology. *MAPS,* 48: 241-269.

Harrison, T.M., Lovera, O.M., 2013. The multi-diffusion domain model: past, present and future. *Geological Society, London, Special Publications*, 378: (in press).

Hilldebrand, A.R., Penfield, G.T., Kring, D.A., Pilkington, M., 1991. Chicxulub crater: a possible Cretaceous/Tertiary boundary impact crater on the Yucatan Peninsula, Mexico. *Geology,* 19: 867-871.

Liu, D., Jolliff, B.L., Zeigler, R.A., Korotev, R.L., Wan, Y., Xie, H., Zhang, Y., Dong, C., Wang, W., 2012. Comparative zircon U–Pb geochronology of impact melt breccias from Apollo 12 and lunar meteorite SaU 169, and implications for the age of the Imbrium impact. *Earth Planet. Sci. Lett*., 319-320: 277-286.

Maher, K.A., Stevenson, D.J., 1988. Impact frustration of the origin of life, *Nature,* 331: 612-614.

Mojzsis, S.J., Arrhenius, G., McKeegan, K.D., Harrison, T.M., Nutman, A.P., Friend, C.R., 1996. Evidence for life on Earth before 3,800 million years ago. *Nature,* 384: 55-59.

Pace, N.R., 1997. A Molecular View of Microbial Diversity and the Biosphere, *Science*, 276: 734-740.

Shoemaker, E. M., 1960. Penetration mechanics of high velocity meteorites, illustrated by Meteor Crater, Arizona. International Geological Congress 21st, Copenhagen: 418-434.

Tera, F., Papanastassiou, D.A., Wasserburg, G.J., 1974. Isotopic evidence for a terminal lunar cataclysm. *Earth Planet. Sci. Lett*., 22: 1–21.

Walter, M.R., Buick, R., Dunlop, J.S.R., 1980. Stromatolites 3,400–3,500 Myr old from the North Pole area, Western Australia. *Nature,* 284: 443-445.

Wielicki, M.M., Harrison, T.M., Schmitt, A.K., 2012. Geochemical signatures and magmatic stability of terrestrial impact produced zircon. *Earth Planet. Sci. Lett*., 321-322: 20-31.