CLIMATIC EFFECT OF IMPACTS ON THE OCEAN.

K. J. Zahnle[1], [1]NASA Ames Research Center (Mail Stop 245-3, Moffett Field CA, Kevin.J.Zahnle@NASA.gov).

Introduction: Impact-generated spherule layers provide information pertinent to the environmental consequences of very large impacts on Earth. The spherules are condensed from high velocity impact ejecta ballistically distributed worldwide. These ejecta comprise material from both the impacting body and the target. Much of this material was vaporized or atomized (in the sense of small droplets of fluid, although doubtless some of the vapor species were atomic) in the impact event, cooled and condensed, and then was re-melted or partially evaporated again on re-entry into the atmosphere far from the crater. The energy deposited in the atmosphere by the re-entering ejecta heat the stratosphere where the particles stop to the temperature of hot lava, and thermal radiation from the superheated stratosphere heats the lower atmosphere, any land surfaces, and the evaporate the surface of the ocean; how hot the atmosphere gets and how much water gets evaporated depends on the scale of the impact. The molten or solid raindrops and hailstones eventually fell out of the atmosphere and onto land or into the ocean over the course of hours and days to pile up as spherule beds, and later the finer dust falls out over months and years.

The most famous example of a spherule layer is in the global boundary clay deposited by the K/T impact 66 Ma. In Europe, far from the Chicxulub crater in the Yucatan, the layer is about 3 mm thick comprising 0.25 mm spherules. The iridium in the boundary clay was the first-discovered signature of a cosmic impact. The chromium isotopes in the spherules imply that the impactor was kin to carbonaceous chondrites [1].

It is still somewhat astounding to learn that there are of order ten spherule layers as thick or thicker than the K/T layer known from the Archean [2-5]. There are four or five layers in the Late Archean ca 2.5-2.7 Ga. The Paraburdoo layer, perhaps the most interesting because it was deposited in quiet waters that must have been very far from the crater, is 2 cm thick and very Ir-rich, so much so that the spherules are of order 50% exogenic by mass [4]. Here the Cr isotopes indicate and affinity with ordinary chondrites. There are another 4-8 layers in the Barberton Greenstone Belt with thicknesses ranging from 10 cm to more than 100 cm [5]. To the extent examined, the Cr isotopes suggests carbonaceous chondritic material. The S3 layer ca 3.24 Ga is 25 cm thick, distal, and iridium-rich; and the S5 layer ca 3.25 Ga may record an impact ten times bigger. If these local estimates of spherule bed thickness are extrapolated globally, they suggest that these to impact events were comparable in energy release to those that formed the lunar Orientale and Imbrium impact basins 500 million years earlier.

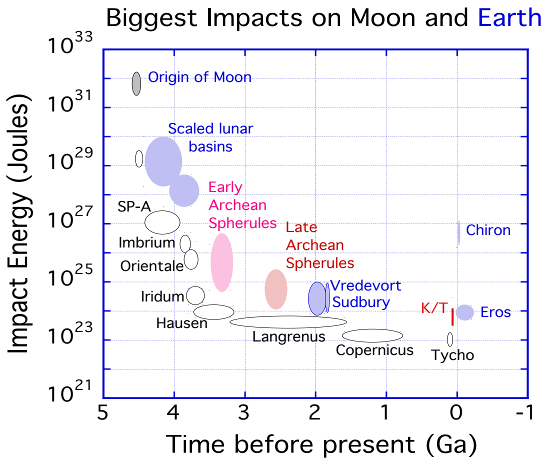

Figure 1. Looking backward: the history of the biggest impacts on the Moon and Earth. The Archean spherules are usually taken to imply that at least ten impacts as big or bigger than the K/T (Chixculub) took place between 2.5-3.5 Ga. Looking forward: the chance that Eros strikes Earth is of the order of 10%, the chance that Chiron strikes Earth is on the order of 0.0001%. Adapted from [6].

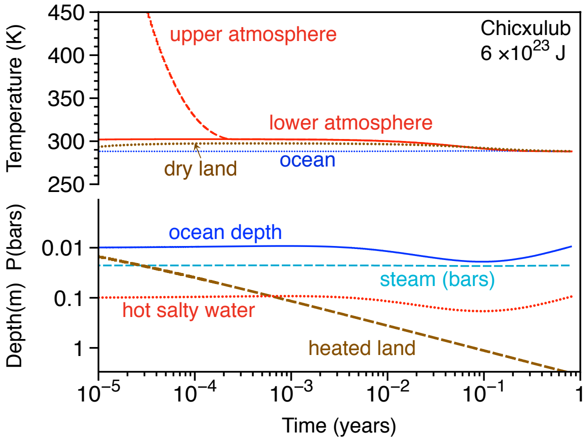

Figure 2. Short-term heating by a high-energy Chicxulub (K/T) impact. The modeled impact is of a 20 km asteroid at 15 km/s striking a 300-m deep shallow sea. The energy released by the impact falls just short of causing major direct thermal perturbations. Most of the environmental consequences came later from the

impact winter induced by the blocking of sunlight by dust, smoke, and sulfate.

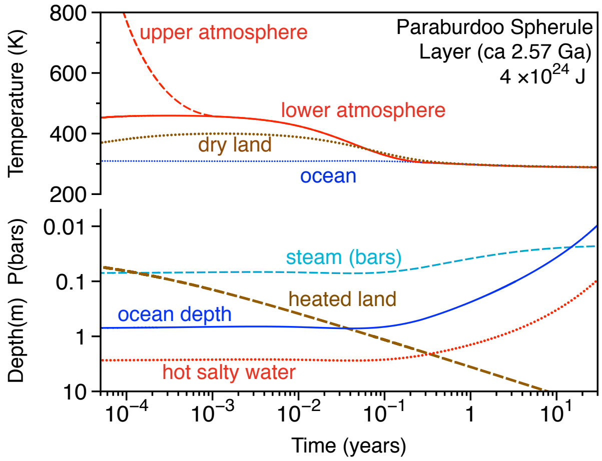

Figure 3. Global environmental evolution after the impact that created the Paraburdoo spherule layer. The upper meter of the ocean is evaporated, which leaves a 2 meter residuum of salty water that floats because it is hot. Thermal radiation from impact ejecta stopped in the atmosphere raise the surface temperature of dry land to 400 K and the troposphere may reach 450 K. The thermal wave from the hot surface penetrates a meter or two into the ground.

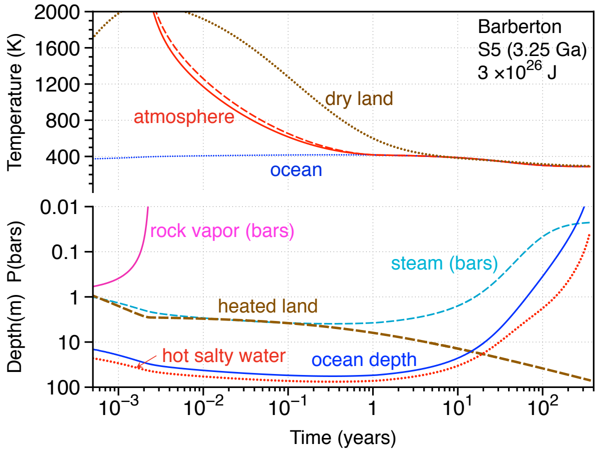

Figure 4. The Barberton S5 spherule layer is the thickest spherule bed and, if globally representative, is by inference the largest impact reported by [5]. In this simulation dry land surfaces melt and flow. The sterilizing thermal wave penetrates 10 meters into the ground. Fifty meters of water evaporates from the seas leaving 70 meters of hot salty water on top of the ocean (which stays cool at depth). The surface temperature even over the oceans is hot (400 K), a temperature that adds 3 bars of steam to the atmosphere.

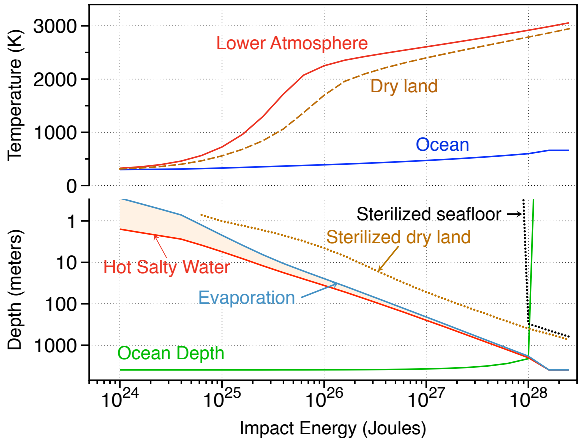

Figure 5. Impacts on Earth, from Chicxulub to the remote possibility of Ceres. The top panel shows the highest temperatures reached in the troposphere, at the ocean's surface, and on land. The bottom panel shows the depth of ocean water evaporated; the depth to which the ocean is sterilized by hot salty water; the depth to which dry land is sterilized; and the depth to which exposed oceanic crust is sterilized. Sterilization is defined as temperature exceeding 400 K. A more nuanced model would show that adverse environmental effects are patchy and thus the planet more habitable after enormous impacts than evident here.

Summary. In the Late Archean 2.5-2.7 Ga, impact events such as the one that deposited the Paraburdoo Spherule Layer, heated land surfaces to 400 K. Conditions were not conducive to mesophilic photosynthesizers on land. The bigger Barberton Greenstone Belt spherule layers (S3, S5), when fully extrapolated, correspond to the lands being sterilized and surface waters heated to 330K (S3) or even to 400 K (S5). Lowe & Byerly [5] describe more extreme environmental consequences that would be commensurate with an Imbrium scale impact (>3x10^{26} J, >100 km diameter impactor), whcih would correspond to a global ejecta layer on the order of 10 m, although the evidence seems more consistent with ~ 1 m.

References:

[1] Kyte F. et al. (2003) *Geology 31,* 283–286. [2] Lowe D. et al. (1986) *Geology 14,* 83-86. [3] Simonson B.M. and Glass B. (2004) *Ann. Rev. Earth Planet. Sci. 32*, 329–61. [4] Lowe D. and Byerly G. (2015) *Geology, 90,* 1151–1154. [5] Simonson M. M. et al. (2010) *LPSC 41,* 2386. [6] Sleep N.H. et al. (1989) *Nature 342,* 139–142.