ELUCIDATING THE FORMATION OF ARCHEAN-PROTEROZOIC BOUNDARY SPHERULE LAYERS. N. Artemieva[1,2] and B.M. Simonson[3], [1]Planetary Science Institute, Tucson, AZ 85719 USA [2]Institute for Dynamics of Geospheres 119334 Moscow, Russia, artemeva@psi.edu, [3]Geology Dept., Oberlin College, Oberlin, OH 44074 USA, bruce.simonson@oberlin.edu

Introduction: The Hamersley and Griqualand West Basins of Western Australia and South Africa, respectively, contain thick successions of well preserved marine strata deposited around the time of the Archean-Proterozoic boundary, APB [1,2]. Close stratigraphic similarities and recent paleomagnetic studies suggest the two successions formed in a single large basin on the edge of possibly the first large continent on Earth. Spherule-rich layers from a minimum of 4 large impacts that happened between ~2.63 and 2.49 Ga have been identified in Western Australia, 3 of which have been correlated to layers in South Africa believed to have been formed by the same impacts [3].

Our main goal is to reconstruct the parameters of impact events (e.g., energy of impact, projectile and target characteristics, and impact flux) around the APB by combining geological data on global spherule layers in South Africa and Australia with numerical models. To benchmark this approach, we begin with a well-studied K-Pg event where both, the crater and its global ejecta, have been studied in detail [4-6].

Numerical model: We model high-velocity phenomena with the 3D hydrocode SOVA [7] complemented by the ANEOS equation of state for geological materials [8]. In three separate stages we reproduce: 1) the impact and initial ejection of material; 2) the ballistic continuation of ejecta on a spherical target; and 3) ejecta as it re-enters the atmosphere [9].

Chicxulub global layer: The layer at the K-Pg boundary is widely recognized as global ejecta from the Chicxulub crater in Mexico. Standard numerical model [10] for crater formation and global ballistic ejecta dispersal predicts the following: 1) that weakly shocked sediments prevail in global ejecta; 2) that projectile material be restricted to ejecta in a narrow fan downrange; 3) that basement ejecta are restricted to a radius of 1000-2000 km from the crater; and 4) that ejecta thickness should vary as a function of azimuth and distance from the crater. These are not consistent with the observed properties of the K-Pg layer, e.g., shocked quartz grains are globally dispersed and the layer has a uniform global thickness of 2-3 mm. These substantial discrepancies suggest the interaction of the ejecta with the atmosphere during re-entry may be of crucial importance in modifying ejecta distribution on a global scale.

Dispersion of ejecta: Up to distances of 2000 km from the crater, ejecta are deposited rapidly without substantial deviation from ballistic trajectories. At larger distances, heating by re-entering ejecta creates strong atmospheric flows in the upper atmosphere that can disperse small fragments (molten spherules and shocked quartz grains of < 1 mm in diameter) preferentially downrange for large distances. According to the model, two-three hours after the impact, small ejecta fragments may have traveled up to a few thousand km beyond their nominal re-entry site based solely on ballistic calculations. After that, their final deposition through the dense lower atmosphere or ocean may take days or weeks. This mechanism is similar in some ways to horizontal dispersal of volcanic aerosols in stable atmospheric winds, but it is much more intense. A more analogous mechanism (atmospheric skidding) has been suggested to explain re-entering ejecta after the Shoemaker-Levy 9 Comet impact on Jupiter [11].

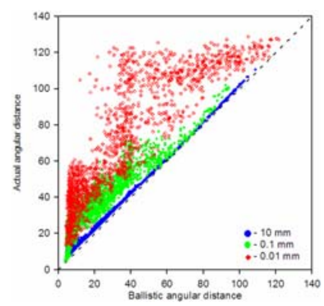

Fig. 1. Final position of particles versus ballistic estimate. 1-cm-particles (blue) are deposited ballistically, 0.1 mm-particles are dispersed up to 2000 km, smaller particles are distributed globally.

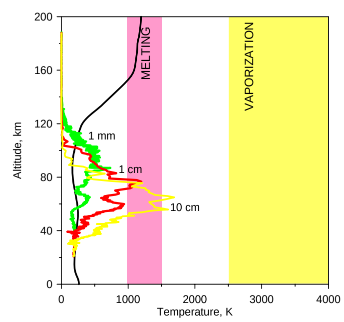

Fig. 2. Maximum temperature of 1-mm particles entering the atmosphere at 5 km/s and creating deposits of various thicknesses (numbers near the curve).

Re-melting and thermal decomposition of ejecta: The temperature of an isolated particle entering the atmosphere is defined by the Whipple law [12] and depends on particle velocity and local atmospheric density. Ejecta re-entry velocity is substantially lower than velocity of cosmic particles, hence, mm-sized fragments reach the surface without any substantial heating whereas cm-sized particles may be partially molten (Australasian tektites represent these partially molten fragments). If ejecta particles reentry the atmosphere in massive numbers, much higher temperatures may be attained. Calculations for the K-Pg impact indicate the ejecta did not generate temperatures high enough to initiate wildfires [13], but within a distance of 5000 km, temperatures may have been high enough to cause re-melting and partial vaporization of silicate particles and thermal decomposition of calcite during initial re-entry – see **Fig. 2.** This result shows that to understand the spherules that dominate distal ejecta layers, we have to take into account reactions between different components of ejecta not only within an impact plume (which expands and cools within a minute), but also during the re-entry (where particles maintain higher temperature for tens of min).

Secular changes in spherule textures: The textures of spherules in APB and Early Archean ejecta seem to differ statisitically from those in younger layers [14]. This suggests a systematic difference in the chemical composition and/or crystallization history of spherules formed in the Archean vs. later in Earth history. One contributing factor is that terrestrial target rocks were probably more mafic on average during the Archean than later in Earth history.

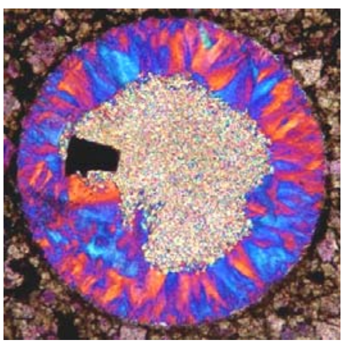

Fig. 3. Typical spherule from Bee Gorge SL (2.54Ga, Hamersley Basin) between crossed -polarizers with gypsum plate inserted; spherule is ~0.3 mm in diameter, has rim of fibrous K-feldspar, and central glass core was replaced by sericite + pyrite crystal.

The model presented here suggests a second factor. The fact that large impacts generate much greater numbers of ejecta particles than small impacts means that the spherules from large impacts will experience much more heating during re-entry (Fig. 2). This in turn suggests spherules from larger impacts will be more extensively crystallized via thermal devitrification and/or wholesale melting during re-entry than spherules from smaller impacts. Several lines of evidence suggest Archean impacts were larger on average than younger ones [15-16]. The crystallized rims that are typically found on APB spherules but rare on younger spherules could perhaps represent a case of heating intermediate between larger (on average) impacts in the Early Archean and smaller impacts later in Earth history.

Comparison with lunar records: There are no large lunar basins younger than 3.8 Ga. Nonetheless, in the range of 100-200 km, there are 5 craters for the Eratostenian era [17]. A projectile of the same size and velocity produces a terrestrial crater which is 20% smaller than a lunar crater. Neglecting this difference and noting that the Earth's surface is 14 times larger than the lunar surface, we may expect 4-5 craters larger than 100 km on Earth within the APB time interval (0.14 Ga). Standard crater size-frequency distribution [18] results in 1 crater with a diameter of 200-600 km within that population. Therefore the observed frequency of spherules layers does not seem unreasonable.

Scaling to larger impacts. Ejecta thickness increases as projectile size cubed [19]. If all of the APB layers represent distal ejecta, projectile diameters should be in the range from 30 km (for a 2-cm-thick global layer) to 70 km (for a 20-cm-layer) up to 150 km (for a 2-m-layer). However, some of the thickest APB layers may represent not global, but proximal ejecta, deposited mainly ballistically. For example, the aggregate thickness of the ejecta in the Carawine spherule layer in Western Australia is ~30 cm, but it contains irregular melt particles up to 2 cm across as well as spherules [20].

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