Spatial Variation of Maximum Spherule Sizes in Distal Ejecta Layers Around the Archean-Proterozoic Boundary

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Spherules are roughly millimeter sized beads of formerly molten glass formed from vaporized rock during large meteorite impacts. Thanks to their distribution in wide, even global layers, they are useful for studying impacts dating from the Archean where subduction and other geologic processes have removed most other traces they would have left in the crust. We studied three sets of layers correlated between two intercontinental basins located in the Pilbara and Kaapvaal cratons to try to estimate their proximity to the sites of impact, get a sense of the relative paleogeographic positions of these two continents during the Archean, and improve our understanding of impacts as a whole.

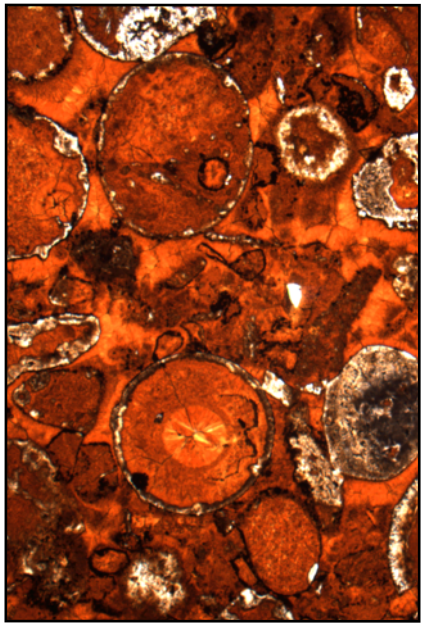
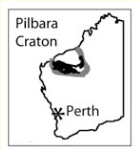


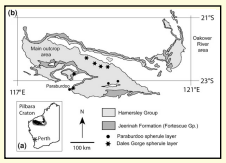
Photo of spherules from the Dales Gorge Spherule Layer under plane-polarized light

Two Important Basins:

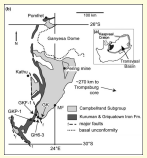
Spherules were collected from three layers in the **Hamersley Basin** in Western Australia and three layers they have been correlated with in the **Griqualand West Basin** of South Africa.

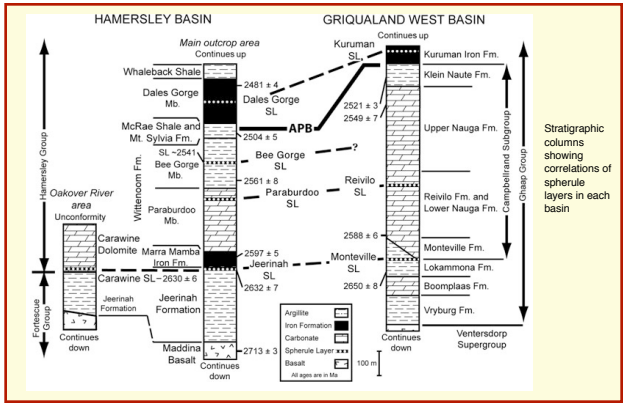


Hamersley Basin, Western Australia
Dales Gorge Spherule Layer (~2.49 Ga) - 12 sites
Paraburdoo Spherule Layer (~2.57 Ga) - 3 sites
Jeerinah/Carawine Spherule Layer (2.63 Ga) - 4 sites



Griqualand West Basin, South Africa
Kuruman Spherule Layer (~2.49 Ga) - 2 sites
Reivilo Spherule Layer (~2.57 Ga) - 3 sites
Monteville Spherule Layer (2.63 Ga) - 9 sites

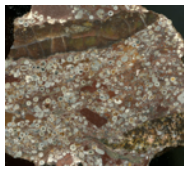




Stratigraphic columns showing correlations of spherule layers in each basin

Methods:

The long axes of spherules and irregulars were measured in thin section using a petrographic microscope. Samples were taken from as many locations as possible for each layer. We measured the 50 largest spherules from populations of 500 from one sample from each location that had the largest, most abundant spherules. The average maximum long axes measurements from all available locations were compiled to obtain the maximum size of spherules in each basin.



Scan of a sample taken from the Monteville Spherule Layer

Impact Sites:

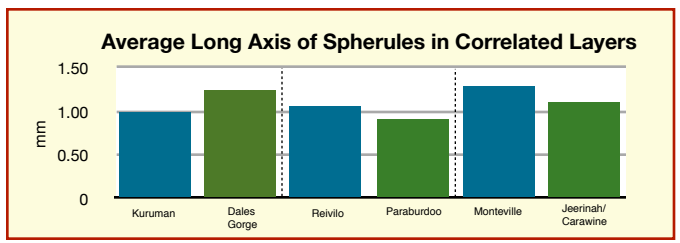
Based on our measurements, there are subtle but noticeable differences in the maximum sizes of the spherules between layers correlated between the two Basins (see chart). Assuming the spherules decrease in size with increasing distance from their source crater, this would indicate which of the two Basins was closer to the crater at the time of impacts [1]. However, there is considerable variability in the maximum sizes of the spherules from location to location within a Basin where multiple locations are available for study (see "Estimating Impactor Size" for further discussion.

Kuruman-Dales Gorge: crater closer to **Hamersley Basin**

Reivilo-Paraburdoo: crater closer to **Griqualand West Basin**

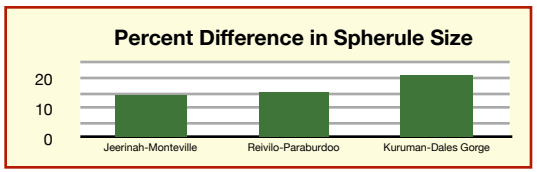
Monteville-Jeerinah/Carawine: crater closer to **Griqualand West Basin***

**The presence of irregular particles, which we interpret as proximal ejecta [6,7], suggests that the Hamersley Basin was closer to the oldest site of impact, but the larger spherules in the Griqualand West Basin suggest that the opposite is true. Perhaps the irregular particles are the result of the Hamersley being hit by a ray of coarser ejecta at a further distance from the crater.*



Paleogeography:

It has been debated whether these two basins were part of the same continent at the time the spherules were deposited [9 and refs therein]. We find some evidence supporting the separate continent theory in the consistent increase in the difference in spherule sizes from the oldest to the youngest layers attained by dividing the smaller spherule size by the larger (see chart).This difference could be explained by the two basins having drifted progressively further apart during the Neoarchean. However, this explanation seems unlikely for a few reasons. One is the distance that could be put between the basins during the approximately 140 million years between impacts. If the basins were on separate continents with an intervening mid ocean ridge, a typical spreading rate of 5 cm per year would put ~15,000 km between basins during the time span represented by all of the impacts. This would presumably result in a much greater change in spherule size than what is observed. This distance also seems unreasonable in light of the stratigraphic similarity of the two basins [9,10]. We conclude that the two basins were located on the same continent during deposition of all the spherule layers, and that the change in spherule size is the result of something other than progressive changes in relative distance between them.



Estimating Impactor Sizes:

Maximum spherule size has been used to help estimate impactor size [e.g. 5]. The accuracy of this method depends on the spherule's maximum size staying consistent throughout the whole distal layer [e.g. 8]. If that were the case, impactor size estimates based on spherules from different locations of a given layer should be the same. However, spherule sizes are not consistent location to location in the layers we studied, despite the fact that these are mainly distal layers [1]. This has lead estimates of impactor size to vary depending on where the samples came from [5]. This could be the result of mixing with proximal ejecta (e.g. Jeerinah-Monteville layer), small sample size (e.g. Kuruman Layer), and/or detrital reworking by impact induced waves and currents (e.g. Dales Gorge Layer). It is also possible that the assumption of uniform maximum spherule size in the distal layer is an oversimplification; few distal ejecta layers from large impacts have been sampled over such a large area.

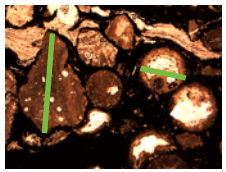


Photo showing long axes measured on an irregular particle (1.8 mm) and a spherule (0.84 mm) from the Jeerinah spherule layer.

Conclusions:

- Spherule size can be used to determine the relative proximity of multiple basins to an impact site.
- Faulty assumptions about the uniformity of distal ejecta layers and/or mixing with proximal ejecta may cause variation in impactor size estimates.
- Despite the observed variations in spherule size, it appears that the Hamersley and Griqualand West Basins were probably on the same continent when the spherule layers were deposited.

References:

[1] Glass B. P. and Simonson B. M. (2013) Distal Impact Ejecta Layers: A Record of Large Impacts in Sedimentary Deposits. Springer. [2] Simonson B. M. et al. (2009) Precamb. Res. 169 100-11. [3] Simonson B. M. et al. (2009) Precamb. Res. 175, 51-76. [4] Hassler, S. W. et al. (2011) Geology 39, 307-310. [5] Johnson B. C. and Melosh H. J. (2012) Nature, 485, 75-77. [6] Simonson B. M. et al. (2000) Impacts and the Early Earth. Springer-Verlag, 181-214. [7] Jones-Zimberlin S. et al. (2006) So. Afr. J. Geol., 109, 245-261. [8] Smit J. (1999) Ann. Rev. Earth Plan. Sci. 27, 75-113. [9] de Kock M. O. et al. (2009) Precamb. Res. 174, 145-154. [10] Beukes N. J. and Gutzmer J. (2008) Reviews in Economic Geology, 15, 5-47.