CHEMICAL ANALYSIS OF IMPACT SPHERULES FROM THE ZAONEGA FORMATION, KARELIA, RUSSIA AND IMPLICATIONS FOR VREDEFORT ORIGIN

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Introduction: Impact spherules in the drill cores from the Zaonega Formation, Karelia, Russia obtained in the frame of the International Continental Scientific Drilling Program's (ICDP) Fennoscandian Arctic Russia – Drilling Early Earth Project (FAR-DEEP), have been recently described [1] with a possible relationship to the Vredefort impact. Initial evidence for a relationship with the 2020±1 Ma [2] Vredefort event was mainly based on the age constraints of the Zaonega Formation, including a stratigraphically higher gabbro intrusion with Sm-Nd age of 1980±27 Ma [3] and a Re-Os age of 2050±20 Ma from the upper part of the Zaonega succession [4]. New geochemical evidence from electron microprobe, micro X-ray fluorescence (µXRF), neutron activation analysis (INAA), and inductively coupled plasma mass spectrometry (ICP-MS) provide a geochemical support for extraterrestrial origin of spherules. Additionally, petrographic observations of the spherules offer constraints on the size of the impactor generating the spherules and on the distance of the spherules from the impact location, which roughly matches with the paleomagnetic estimates of the distance between the Kaapvaal Craton and the Fennoscandian Shield of approximately 2000 km.

Petrography: Spherules were discovered in two drill cores (12A and 13A), located approximately 23 km from each other. Spherules occur in two stratigraphic intervals in core 13A. The upper section has a high density of spherules in the interval from 26.51 m to 27.74 m, and the lower section from 66.83 m to 67.33 m. Core 12A has only a single interval of spherules from 4.08 to 4.27 m with a lower density of spherules. Spherules appear to be restricted exclusively to these intervals within the core. The two intervals in core 13A could represent repetition due to faulting. In the upper interval, the surface of the split core revealed 5068 distinct spherules in an area 2.5 cm by 123 cm.

Spherules have a variety of petrographic expressions, mostly being circular (spherical) to slightly ovoid. About 5% have irregular shapes, such as teardrops and dumbbells (Fig. 1). Spherules are on average about 850 µm in diameter, although some spherules reach up to 1.5 mm in size. The smallest spherules are about 200 µm, although it is unclear if smaller objects would have survived the diagenetic and alteration processes that have affected these samples.

The samples have experienced recrystalization of carbonate minerals, as well as some level of hydrothermal alteration. There are clearly two generations of silicates in the spherules, with one generation representing silica introduced by hydrothermal alteration and the other representing devitrification of the silicate glass formed from the impact (Fig. 2). Silicates are primarily present as various compositions of biotite. Alteration most likely took place in reducing conditions, based on the presence of abundant pyrite, gersdorffite, and various Ti phases (mostly rutile and anatase, with minor brookite, based on Raman spectroscopy). Despite the mineralogical alteration, many of the spherules preserve original textures, including botryoidal internal textures and quench textures on the outer edges, suggestive of rapidly cooling liquids (Fig. 3).

Geochemistry: Analyses by electron microprobe, µXRF, and INAA were performed at the University of Vienna. Defocused beam microprobe analyses of silicates show a high and low Mg variety of biotite. The high-Mg biotite has 22-24 wt.% MgO, while the low-Mg biotite has 5-12 wt.% MgO. The low-Mg biotite also has 8-10 wt.% less Al2O3, 1-2 wt.% more K2O, and 5-9 wt.% more SiO2 in comparison to high-Mg biotite. Hydrothermal veins in the samples have compositions consistent with the low-Mg biotite, suggesting (along with petrographic indications) that this phase has formed during hydrothermal activity.

µXRF analysis shows that Ti phases are all located within spherules, perhaps indicating a higher initial Ti content of the spherules than the matrix. The spherules are enriched in Cr and Ni. Samples are enriched in LREEs and depleted in HREEs, with minor Eu anomalies in some of the samples.

Platinum group elements (PGEs) were determined by ICP-MS using the fire assay method [5]. PGEs show a slight elevation above continental crustal values (0.03 ppb Ir [6]), with up to 0.11 ppb of Ir. The more sensitive measure of extraterrestrial contamination of samples is to compare Ru/Ir, which gives a value of 1.5, as compared to chondrite, which has Ru/Ir = 1.25, while continental crust has Ru/Ir = 10 [7].

Discussion: The new geochemical evidence from the Karelian spherules confirms an extraterrestrial origin for the samples. Despite the low absolute values of PGEs, the element ratios cannot easily be explained by a terrestrial origin.

What is less clear is how this new evidence sheds light on the question of the relationship of the spherules to the Vredefort impact event. The low PGE content is comparable to that of the Vredefort granophyre [8], although a direct comparison between melt generated as spherules and melt emplaced deep within the crater is problematic. The composition of the spherules is grossly similar to the mafic granulites of the Vredefort target material, although the wide variety of compositions included in the target makes it unlikely that a similar composition could not be found. The geochemical data are consistent with a Vredefort origin, but do not exclude other scenarios..

The size of spherules offers some constraints on the amount of energy involved in the impact plume where the spherules were formed [9]. Assuming a 20 km/s velocity for the impactor, equations given in [9] predict an impactor of 20 km diameter, consistent with the size range of the Vredefort impactor. Similarly, the thickness of a spherule bed can be used as an indicator of distance from the impact [9], and the thickness of spherules in the upper interval of core 13A predicts a distance of 2400-3200 km from the impact site, which is consistent with the estimates of the distance between the Kaapvaal Craton and Karelia at the time of the impact [10]. Therefore, several lines of evidence are permissive of the spherules being derived from the Vredefort impact, though none of these lines of evidence is conclusive.

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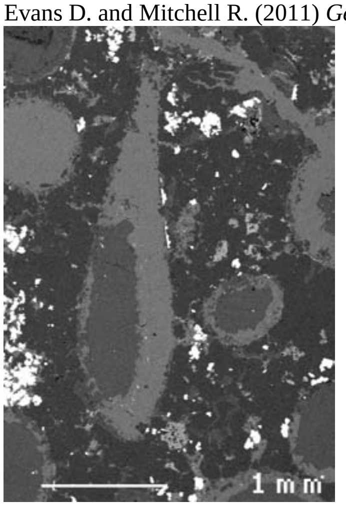

Figure 1: Teardrop-shaped spherule in backscattered electron image. Sample from 27.10 m in core 13A.

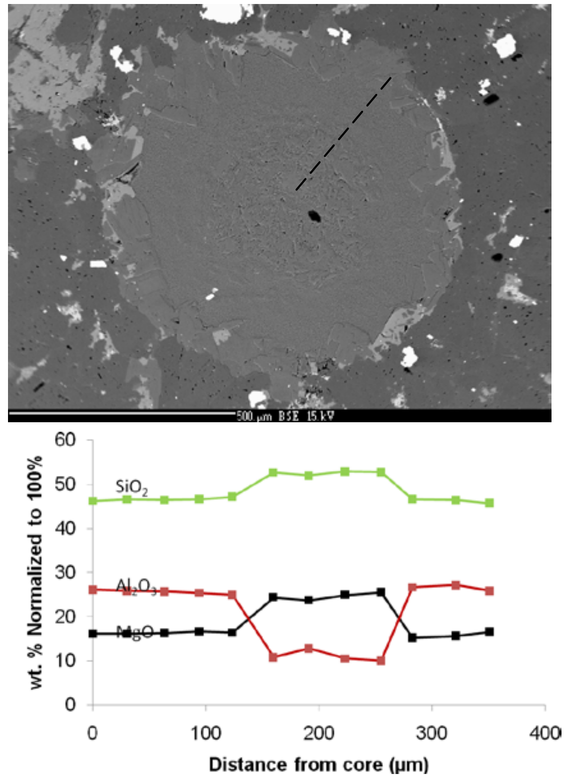

Figure 2: A) Layered spherule from 27.05 m in core 13A in backscattered electron image. B) The variation in composition of the spherule. Line scan correlates to the dashed line in Fig. 2A.

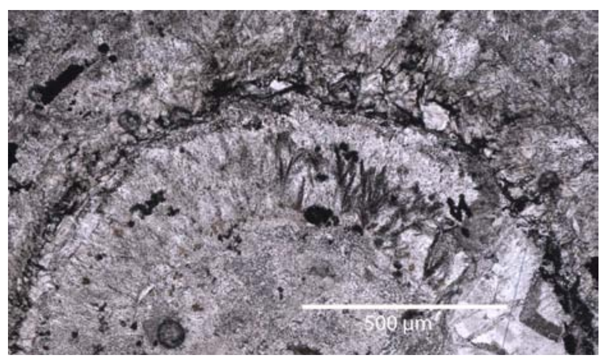

Figure 3: Relict textures visible on the edge of a spherule suggest rapid cooling of a glass phase. Sample from 67.21 m in core 13A.