POSSIBLE OCCURRENCE OF DISTAL IMPACT EJECTA FROM THE VREDEFORT IMPACT EVENT IN DRILL CORES FROM THE ONEGA BASIN, RUSSIA. M. S. Huber[1], A. E. Crne[2], A. Lepland[2], V. A. Melezhik[2,3], C. Koeberl[1,4], and the FAR-DEEP Science Team. [1]Department of Lithospheric Research, University of Vienna, Althanstrasse 14, Vienna, Austria, A-1090, matthew.huber@univie.ac.at, [2]Geological Survey of Norway, Postboks 6315 Sluppen, N-7491 Trondheim, Norway.[3]Centere for Geobiology, University of Bergen, Postboks 7803. N-5020 Bergen. [4]Natural History Museum, Burgring 7, A-1010 Vienna, Austria.

Introduction: Drill cores taken from the Paleoproterozoic Onega Basin, Karelia, Russia (62º N, 35º E), in the Fennoscandian Shield, targeted a succession of organic carbon-rich sediments (often referred to as shungites) as part of the ICDP FAR-DEEP drilling project, contain an interval of possible impact spherules. The Karelian succession containing spherules is stratigraphically above carbonate rocks of the Lomagundi-Jatuli carbon isotope excursion, which ended 2060 Mya [1], and the youngest deposits in the basin are 1970 Ma [2].

Spherules are found in two drill cores from FAR-DEEP Holes 12A and 13A, as well as one additional exploratory drill core from the same region (drill core 221, drilled in 1975 [3]). Core 13A is located approximately 23 km from the other two cores, which are separated by 3 km. Spherules occur in two stratigraphic intervals. The lower section, located at depths from 67.33 m to 66.83 m, is poorer in spherules. The upper section has a high density of spherules in the interval from 27.74 m to 26.51 m A single clast of dolostone at 71.10 m contains a handful of spherules. Core 12A has only a single interval of spherules at 4.08 m with a low density. Core 221 is not fully preserved for examination, but individual samples from 47 m, 59 m, and 61 m contain scattered spherules. Spherules appear to be restricted exclusively to these intervals.

Spherules are round to ovoid <1.5 mm features grossly resembling ooids. Some spherules have aerodynamic teardrop shapes, broken rims, or a "fused" appearance (Fig. 1). The spherules are contained in a dolostone matrix with thinly dispersed organic carbon. Organic carbon occurs as *in situ* kerogen and as pyrobitumen, representing remobilized hydrocarbons migrating into host rocks[4] The lithologies above and below the spherule intervals are dolostone breccias with organic-rich matrix, dolostones, cherts, organic-rich mudstones, and some greywacke and conglomerate. .

Mineral phases: Mineral phases were identified in thin sections using petrographic microscopy and scanning electron microscopy with energy dispersive spectrometry. Spherules are mineralogically zoned, with similar zones found in most spherules. Spherules have an outer thin (<10 µm) rim of apatite that seems to outline the original outer extent of the features. Spherules are partially or totally replaced by calcite. Calcite seems to prefer the outer edge of spherules, with the least altered spherules having only a small part of the outer rim altered to calcite, and more altered spherules having thick rims of calcite with only a small core of other minerals remaining. For spherules with only a thin zone of calcite replacement, there is a double interior of K-Al-Mg clay minerals (Figs. 2, 3). The outer clay layer has tightly packed clay crystals with little intervening space and only minor fractures. The inner layer of clay is less dense, with botryoidal patterns visible in the interiors. The two clay segments are commonly separated by concentric fractures. The inner layer of clay may contain small quantities of organic carbon in black phases on SEM-BSE images (Figs. 2, 3) .

Several minor mineral phases are present within the spherules. Pyrite crystals are abundant in the cores, but in spherules, they are usually found as inclusions within the calcite segment. Rutile is present within the spherules, but has not been identified in the matrix between spherules. Rutile usually is <30 µm, and, in some cases, is present in the form of euhedral elongate crystals (Fig. 3). A 50 µm Ni-As phase with skeletal euhedral tetragonal crystals is rarely present in the outer clay layer. Anhedral monazite has been found in the outer clay, though all crystals identified thus far are <10 µm in size.

Discussion: The combination of broken rims, aerodynamic shapes, and mineralogy within spherules distinct from the matrix suggest that the Fennoscandian spherules could be of impact origin. These spherules meet several of the criteria for impact spherules outlined in [5]. Both the broken rims and double layer of clay replacement are indicative of originally hollow glass spherules. The spherules have different mineral phases than are located in the matrix between the spherules, suggesting a difference in chemistry between the features and the host rocks, which is consistent with the impact interpretation. There are no significant differences between the petrographic characteristics of spherules at the different locations or intervals. The maximum thickness of deposits is 1-2 meters, consistent with the thickness observed in other spherule layers [5].

The main difficulty with an impact interpretation is the double concentration of spherules in core 13A. An impact should result in a single period of deposition, and it is highly unlikely that two large impacts of a variety that can generate large amounts of distal ejecta would occur within 90 million years. There are multiple possible scenarios that still allow for the impact interpretation. The deposits are hosted in a set of mass-flows. It is possible that, as spherules began accumulating, a mass flow was generated, separating spherules that were already deposited (lower deposit) from spherules later deposited (upper deposit). Another possibility is that the upper spherules are reworked. A third possibility is that the section is repeated by an obscured fault. Unfortunately, there is only one core that preserves both spherule intervals, so it is difficult to constrain the specific scenario that took place. Ultimately, the presence of multiple beds does not seem to be a major challenge to the impact interpretation, as evidence outlined above makes other interpretations of the spherules (i.e., ooids, lapilli, coal balls, etc.) less likely.

The age range of 2060-1970 Ma contains only one known impact event, the Vredefort impact crater at 2020 Ma. Proposed Paleoproterozoic paleogeography [6] suggests that Fennoscandia would be the farthest landmass from the Kaapvaal craton at the time of deposition, also consistent with the distal nature of the ejecta. Only one other location of possible Vredefort ejecta has been located [7], though it is not as tightly temporally constrained as this deposit. We hope that further geochemical investigations (in progress) will clarify the nature of the spherules and what their temporal relationship with the Vredefort impact event might be.

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References: [1] Melezhik V. et al. (2007) *Geology*, 35, 655-658. [2] Melezhik V. et al. (2004) *Ore Geology Reviews*, 24, 135-154. [3] Kupryakov S. (1994) In: *Organic matter in shungite-bearing rocks of Karelia*, Petrozavodsk, p. 93-98 (in Russian) [4] Melezhik V. et al. (2005) *GSA Today*, 15, 4-11. [5] Simonson B. (2003) *Astrobiology*, 3, 49-65. [6] Zhao G. et al. (2004) *ESR*, 67, 91-123. [7] Chadwick B. et al. (2001) *J. Geol. Soc. Lond.,* 158, 331-340.

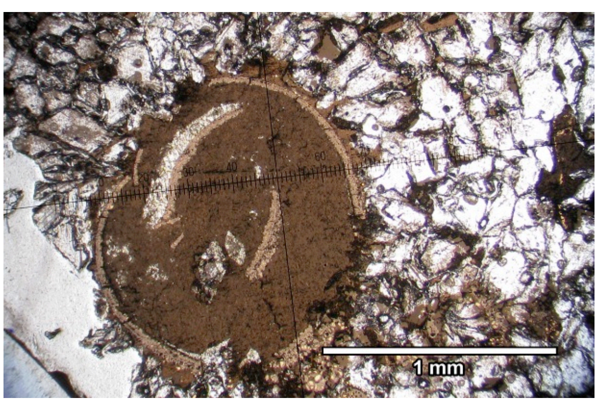

Figure 1: Broken spherule in plane polarized light with reflected light. Sample from 4.08 m in core 12A.

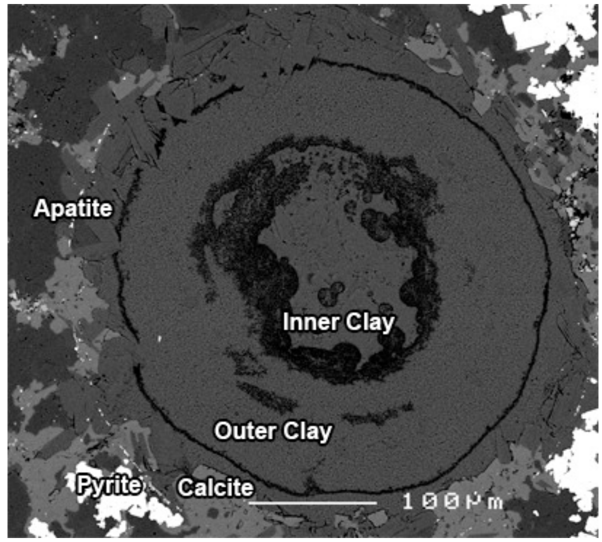

Figure 2: Layered spherule from 26.92 m in core 13A in backscattered electron image. An outer thin layer of apatite seems to indicate the original extent of the spherule. The outer edge is partially altered to calcite. The interior of the spherule has a K-Al-Mg clay phase with concentric fractures and small amounts of organic carbon. The innermost clay has a botryoidal texture, indicating different formation conditions than the outer clay, possibly formation in a hollow core.

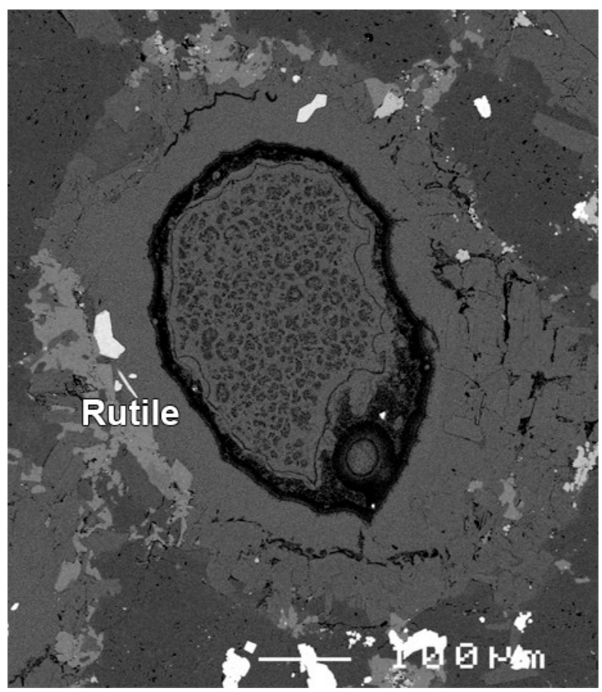

Figure 3: Rutile (white) in the outer rim of layered spherule. The same zones can be observed in most spherules, with an outer layer of calcite, an interior clay, and an innermost botryoidally textured clay. Sample from 26.92 m in core 13A.