SPHERULES IN A PALEOPROTEROZOIC DOLOMITE LAYER IN THE KETILIDIAN OROGEN OF SOUTH GREENLAND ARE CANDIDATES FOR EJECTA FROM THE VREDENFORT STRUCTURE. B. M. Simonson†, B. Chadwick‡ and P. Claeys§, †Geology Department, Oberlin College, Oberlin, OH 44074-1044 USA (bruce.simonson@oberlin.edu), ‡Room 220, Laver Building, University, Exeter EX4 4QE, UK (B.Chadwick@exeter.ac.uk), §Institut fuer Mineralogie, Museum fuer Naturkunde D-10099 Berlin, GERMANY (philippe.claeys@rz.hu-berlin.de).

Introduction: Layers rich in sand-sized spherules of former silicate melt are the most commonly cited evidence of early Precambrian impacts [1,2]. Spherules occur in a single dolomite layer c.1 m thick in the Palaeoproterozoic Grønse Formation in the Ketilidian orogen of South Greenland. The Ketilidian orogen was the result of oblique convergence at c.1800 Ma [3]. The layer is in the upper part of the Vallen Group, a succession of low-grade metasedimentary rocks deposited unconformably on Archaean gneisses of the foreland in the Ketilidian Border Zone between c.2130-1880 Ma [4,5]. The spherule-bearing layer was discovered during mapping in the 1960's and crops out at a constant stratigraphic position for a strike distance > 26 km in Grønsenland and NE Midternæs [6,7]. The Grønse Formation has many dolomitic layers, but spherules were only found in the uppermost one "in spite of exhaustive searching" [7]. In Grønseland, the Grønse Formation is ~100 m thick and consists of dolomite, pyritic and carbonaceous shale, chert, and sills of dolerite.

The spherules were originally interpreted as microfossils and given the name Vallenia erlingi RAUNSGAARD PEDERSEN nov. sp. because of their spheroidal shapes and inclusions of carbonaceous matter [6]. Bondesen and co-workers could find no fossil or living counterpart for Vallenia sp. but were persuaded of its organic affinity by the isotopic composition of carbon in whole rock analyses. A reassessment initiated by BC in 1997 following fieldwork in Midternæs and Grønseland [8] led to our reinterpretation of the spherules as replaced impact ejecta [9]. The analyses presented here were performed on splits of sample GGU 71380 from the Greenland Geological Survey supplemented by observations on thin sections kindly provided by H. J. Hansen. The sample was collected in NE Midternæs by A. K. Higgins in 1965 (locality coordinates: 47° 48'W, 61° 40'N).

General Description: Excluding veins, sample GGU 71380 consists of 73% dolomite, 18% spherules, 6% chert fragments, and 3% epiclastic sand (based on 1835 points counted on a large thin section). The dolomite is an equigranular mosaic of crystals 0.5-1.0 mm across that are intergrown, lack detrital outlines, and often show zoned euhedral cores via cathodoluminescence; we interpret them as late diagenetic crystals.

The epiclastic detritus is well sorted very fine to fine sand, dispersed throughout the sample, and consists largely of monocrystalline quartz with lesser feldspar. Many of the quartz grains have trains of minute inclusions including two-phase fluid inclusions, but we saw no evidence of shock deformation. The chert fragments are up to 4 mm long and diverse texturally. Some contain quartzose silt to very fine sand similar to the epiclastic sand disseminated in the dolomite, but none show the radial-fibrous textures observed in the spherules (described below). Locally, carbonate occurs in more finely crystalline rectangular patches lacking spherules, epiclastic sand, or any other inclusions. We interpret these patches and the chert fragments as intraclastic pebbles. Analysis of 20 gm of the sample using ICPMS yielded 0.02 ppb iridium and no anomalous enrichment in PGEs.

Petrography of Spherules: Most of the spherules are 0.5-1.0 mm in diameter and have circular cross-sections, although a minority have ovoid, teardrop, or bilobate cross-sections. The spherules are not tectonically deformed, but the edges of some are slightly pressure-solved. Internally, the spherules are diverse and consist of two main elements: 1) radial-fibrous aggregates of chalcedony, sericite and/or K-feldspar and 2) blocky quartz crystals c.100 µm in diameter associated with felted to randomly radial-fibrous sericite. The fibrous aggregates radiate inwards towards the centers of spherules and meet along planar to smoothly curved contacts, whereas the blocky quartz crystals and associated sericite have no preferred orientations and disrupt the radiating textures locally. The relative proportions of the two main textural components vary widely and many are invaded by carbonate crystals. At least 6% of the spherules contain dark parallel lines in patterns ranging from orthogonal grids to isolated feathery or cruciform masses. These patterns are strikingly similar to skeletal spinels grown rapidly in silicate melts, including spherules from the K-T boundary layer, but we were unable to detect any X-ray signal from the dark material itself. We therefore believe the lines consist of carbonaceous matter that replaced the original spinels. More rarely, spherules contain dark lines of organic matter (?) in arcuate patterns that resemble perlitic cracks or pseudomorphic patterns similar to devit-
Grænsesø spherule layer appears to fit this pattern, but from more distant continental sources [14]. The this mixes the spherules with both large rip-up clasts ing transport by impact-induced waves and currents; of deep shelf environments was recently proposed involv-
Archean and Paleoproterozoic impact spherules in
the layer indicates the spherules were reworked by
and chert intraclasts and well-sorted epiclastic sand in
in keeping with possible replaced skeletal spinel crystals, perlitic cracks and devitrification spherulites. Moreover, the observed shapes are typical of splash-form microtektites, whereas the layer lacks non-spherical particles with the shapes and textures typical of glassy to scorciaceous volcanic ash. The apparent absence of PGE enrichment in the sample does not rule out an impact origin because many impact glasses show little or no enrichment in iridium or other PGEs [11,12]. The original composition of the Grænsesø spherules is uncertain, but the lack of vesicles and the presence of possible perlitic cracks suggest some were high-silica melts, whereas the possible skeletal spinels suggest others were low-silica melts. Such a wide range in composition is unlikely for particles from a single volcanic eruption, but typical of glassy to scoriaceous volcanic ash. The ap-

glasses show little or no enrichment in iridium or other
non-spherical particles with the shapes and textures
gated shapes and the lack of nuclei and layered corti-
ary lapilli is ruled out by the presence of highly elong-
the spherules as carbonate ooids or volcanic accretion-
fication spherulites. However, we saw no candidates for replaced or infilled vesicles.

Interpretations: It is now known that spheroidal acritarchs with diameters > 1 mm only occur in Mesop

The stratigraphic context of the spherule layer sug-

These sites were c.2000 to 3000 km from the Chixcu-

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Interpretations: It is now known that spheroidal acritarchs with diameters >1 mm only occur in Mesoproterozoic and younger strata [10]. The carbonaceous matter in the Grænsesø spherules does not prove a biological origin either because the spherule-bearing dolomite layer is interbedded with carbonaceous pe-

Implications: The aggregate thickness of Grænsesø spherules is estimated at 18 cm since they make up c.18% of a layer c.1 m thick. This suggests the spherules in the Grænsesø layer are the result of a large impact since the thickest known accumulations of Phan erozoic impact spherules are on the order of 10 cm thick (at two of the K-T boundary layer sites) [15,16]. Roughly 400 impact structures with diameters ≥ 100 km should have formed since 3800 Ma [18], yet impact ejecta layers are quite rare in the stratigraphic record. The Grænsesø spherules are the first candidates for distal impact ejecta recognized in the ~1.9 billion years of Earth history between the 2.49 Ga Dales Gorge spherule layer in Western Australia [2] and the 0.59 Ga ejecta layer from the Acranum Structure of South Australia [19]. The two largest impact structures on Earth, Vredefort (2023 ± 4 Ma) and Sudbury (1850 ± 3 Ma), both formed during this time span [20]. Moreover, they are both larger than the Chixculub Structure, so both should have dispersed ejecta around the globe. The age of the Grænsesø spherules is not well constrained, but they clearly could be distal ejecta from the Vredefort Structure. The dates available are not as favorable for an origin as Sudbury ejecta, but the Ketilidian orogen is currently ca. 2800 km from the Sudbury structure. Based on the K/T boundary layer, this is a distance at which thick deposits of impact spherules can form.