ELEVATED FLUX OF MID-ORDOVICIAN MICROMETEORITES.

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Introduction: A study of micrometeorite flux has been undertaken on a sequence of Cambro-Ordovician shallow marine limestones from Northwest Scotland. The Durness Group limestones are a thick sequence of dolostones, with intervals of limestone [1]. They form the greater part of a Cambro-Ordovician succession commencing with Lower Cambrian quartzites, all overlying Lewisian (Archean) gneisses and Torridonian (Proterozoic) metasediments. The Durness Group consists of seven separate formations, younging through Ghrudaidh (60m thickness), Eilean Dubh (150m), Sailmhor (130m), Sangomore (60m), Balnakeil (140m), Croisaphuill (120m) and Durine (80m).

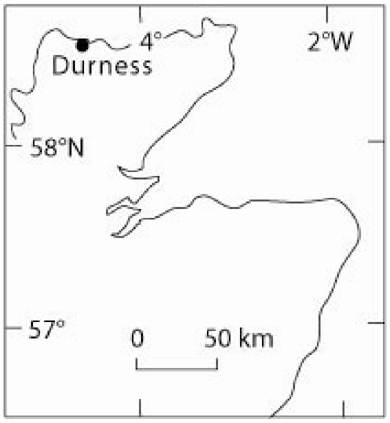

Fig. 1. Location of micrometorite-bearing Durness Group section, Durness village, NW Scotland.

Micrometeorites: The majority of micrometeorites studied are collected from Antarctica, where large numbers of unmelted micrometeorites have been extracted from surface snow [2], ice and meltwater. However many micrometeorites completely melted on entry through the Earth's atmosphere and are known as 'cosmic spherules'. These include silicate/stony (S-type) and iron (I-type) cosmic spherules [3]. I-type spherules are composed of interlocking magnetite crystals with interstitial wüstite, and are less susceptible to alteration, and more prominent in ancient samples [4]. They also have the advantage that they can be greatly concentrated by separation of the acid-resistant magnetic fraction of their host rock, and some have distinctive exterior dendroidal ornamentation.

Since early in the Earth's history, the meteorite flux is assumed to have been more or less constant. However the discovery of numerous fossil meteorites in a mid-Ordovician limestone section in Sweden reflects a period when the flux was up to two orders of magnitude greater than normal [5,6]. This episode is also represented by an iridium anomaly, and microscopic grains of extraterrestrial chromite [7]. The combined evidence reflects break-up of an L-chondrite parent body some time between 500 Ma and 470 Ma, most probably toward the end of this range [8]. Up to 25% of meteorites arriving at the Earth today retain an isotopic record of the break-up event [7], showing that it was one of the most important in delivery of extraterrestrial material to the planet's surface. The impact of this event in the geological record may be global [9]. The deposition of the Durness Group during this timeframe makes it a particularly interesting sequence to search for a micrometeorite record.

Methodology: A sample was collected from each of the seven formations of the Durness Group from the Durness area, Northwest Scotland (Fig. 1). All of the samples collected were whole rocks, to avoid possible contamination from anthropogenic sources. All of the rock samples collected were crushed, and digested in 20% HCl to remove the carbonate content and liberate any micrometeorites. Due to the magnetic nature of some micrometeorites (I-type cosmic spherules), magnetic separation can be used to separate them from the bulk sediment. The magnetic separation was carried out on 100g < 250 µm fraction samples using a hand magnet in a plastic sheath, then the magnetic fraction was examined by SEM/EDX.

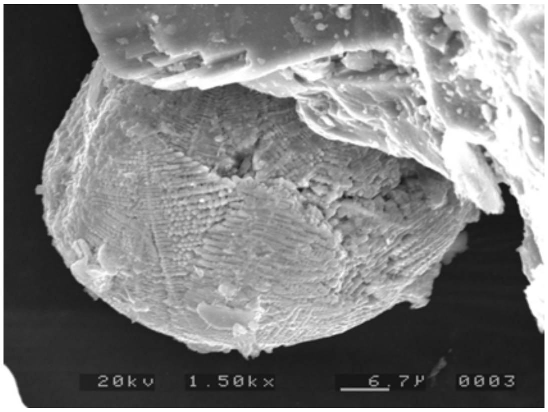

Fig. 2. Micrometeorite from Arenig of Durness, NW Scotland, showing dendroidal microcrystalline structure.

Results: In total nine definite micrometeorites and two possible micrometeorites were found in the limestones (Fig. 2). Four of the definite micrometeorites were found in the Croisaphuill Fm. and five were found in the Balnakeil Fm.. The two possible micrometeorites were also found in the Balnakeil Fm., i.e. all are close to the top of the Durness Group, of Arenig age. The micrometeorites were identified by a dendroidal microcrystalline structure. Very similar structures are described by numerous authors [10]. The size range (10 to 25 µm) is smaller than those in most collections from ice and the deep sea.

The different samples yielded widely varying numbers of magnetic grains. The great majority of grains can be assumed to be detrital terrestrial grains. Two formations yielded an order of magnitude more magnetic grains than most of the others (about 10,000 each). One of these (Balnakeil Formation) yielded several micrometeorites, while the other (Eilean Dubh Formation) yielded none. Four of the other formations yielded between 60 and 115 magnetic grains, of which only the Croisaphuill Formation produced micrometeorites. These data indicate that micrometeorite discovery was not simply a reflection on the number of magnetic particles examined. It would not be wise to conclude that the Durine Formation, which yielded only 8 magnetic grains, did not contain micrometeorites. The micrometeorite-bearing section identified in the Balnakeil and Croisaphiull Formations may, therefore, continue into younger rocks.

Discussion: In this study, rock samples from outcrop were used, minimizing the chance of contamination. The pattern of data also makes contamination very unlikely. All of the micrometeorites come from just two formations, while the other five yielded nothing. The two micrometeorite-bearing formations are also stratigraphically adjacent. This suggests a genuine extraction of micrometeorites from the rocks.

We can assess the flux of micrometeorites, relative to the general flux to the Earth of about one micrometeorite with size >100 µm per square metre per year [11]. The <20 µm size fraction should be about 5 times as abundant for I-type spherules [12], equivalent to a flux of 5 x 10^6 per m^2/Myr. The 11 definite and possible I-type spherules were extracted from a total acid residue of 231g, including the >250 µm material. Before dissolution, this represented 1.49 kg rock, or 7.4 spherules per kilogram of rock. Assuming a limestone density of 2600 kg/m^3, this is equivalent to 19240 spherules per m^3. The combined thickness of the two formations is 260m, deposited over about 10 Ma, giving a mean rate of 26m/Myr. Thus the mean spherule accumulation rate is about 5 x 10^5 per m^2/Myr. The ratio of cosmic spherules to unaltered micrometeorites in Antarctic samples increases with size, representing about 20% in the 50 to 100 µm size fraction [13]. Thus in the size range represented in the Durness Group, we expect the cosmic spherules to represent at least an order of magnitude more unmelted micrometeorites. Only about 2% of the Antarctic cosmic spherules are I-type [12], so the total number of original micrometeorites could be 500+ times as great as the observed number of I-type spherules, thus elevating the rate to 2.5 x 10^8 micrometeorites per m^2/Myr. These estimates indicate a micrometeorite flux in the upper part of the Durness Group about 50 times greater than normal, which is consistent with the mid-Ordovician meteorite flux elevated by one to two orders of magnitude [5-7]. Even if just 2 spherules had been found, the calculated flux would still be an order of magnitude greater than current. At small numbers, we must be careful about use of statistics, but it is not surprising that other formations yielded no spherules if the micrometeorite flux was like that of today.

Conclusions: Nine definite and two possible micrometeorites have been found in 200g of digested rock samples, all from the Balnakeil and Croisaphuill formations. The outer surface of the micrometeorites show a chemical composition consistent with magnetite, and they are classified as I-type cosmic spherules. Extrapolating to micrometeorites in general, their flux in the upper half of the Durness Group is one to two orders of magnitude greater than today.

Limestones studied in southern Sweden yield evidence of a flux of meteorites up to two orders of magnitude greater than today [5-7]. This anomalous flux of extraterrestrial matter is dated at the Arenig-Llanvirn boundary. All I-type cosmic spherules found have been extracted from the top of the Durness Group succession in the Arenig (478-466 Ma). Therefore it is possible that the flux has also been recorded in the Durness Group limestones at around the same time.

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