METEORITIC ABLATION DEBRIS FROM THE TRANSANTARCTIC MOUNTAINS: EVIDENCE FOR A TUNGUSKA-LIKE IMPACT OVER ANTARCTICA.

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Introduction: Aggregates of microscopic spherules were discovered within the ~1 Myr-old Transantarctic Mountain micrometeorite traps at Miller Butte, Victoria Land, Antarctica [1]. They are ca. 500 µm in size and are constituted of spherules less than 65 µm in diameter which are broadly similar to cosmic spherules [2] and meteorite ablation spheres [3] in terms of overall texture and composition.

Samples and methods: The spherulitic aggregates were first observed under a microanalytical Scanning Electron Microscope (SEM). Two particles were mounted on glass capillaries and analysed by synchrotron X-ray diffraction (XRD). The magnetic hysteresis of the same two particles was then measured using a Micromag vibrating sample magnetometer to determine the properties of their magnetic phases. Polished sections were studied using a microanalytical Field Emission Gun SEM for detailed petrographic investigation. The major element bulk compositions of the spherules and their mineral constituents were obtained by Electron Probe Microanalysis (EPMA).

Results: SEM and FEG-SEM observations of the spherulitic aggregates reveal that they are similar to stony and G-type cosmic spherules, and ablation debris. The majority of the spherules are dominated by magnesioferrite dendrites set in a silicate glassy or cryptocrystalline mesostasis. The second most abundant spherule type comprises porphyritic olivine plus magnesioferrite (POM-type). POM fragments (POMF) are also present and may be as large as 65 µm in size, with a mean value of 40 ± 15 µm. Less common are feathered olivine (FO-type), cryptocrystalline (CC-type) and barred olivine (BO-type) spherules.

The spherule frequency by type is DM = 81.6 %, POM + POMF = 16.8 %, FO + BO = 0.8 %, CC = 0.8 %. The range and mean diameter of a representative sample of 1236 spherules are 0.4 - 39.8 µm and 3.7 ± 4 µm.

EPMA analysis show that olivine has a relatively homogeneous compositions $Fa_{16.3 \pm 2.7}$ relative to olivine composition of the cosmic spherules and is nickeliferous (2.48<NiO<2.82 wt%) [4]. Coexisting magnesioferrite is Mg- and Ni-rich (MgO up to 13.4 wt% and NiO up to 4.6 wt%), unlike terrestrial spinel.

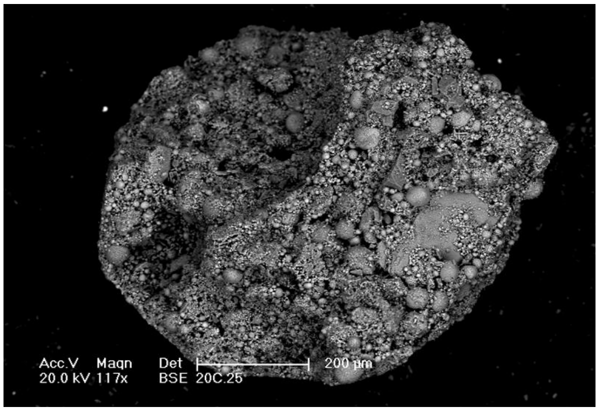

Fig. 1: SEM-BSE image of aggregate #20c.25.

The interior of the sectioned spherules shows null to moderate terrestrial weathering. Jarosite occurs as fine grained encrustations and coating of the spherules, binding them together. The studied sections also contain the relatively large, silicate mineral grains interspersed in the spherulitic aggregates. EPMA analysis showed that they consist of quartz and alkali feldspar minerals observed within granitoids of the Granite Harbour Intrusive.

Synchrotron XRD analysis are consistent with previous observations and show that the relative mineral abundances for the two particles are magnesioferrite 58-55 wt%, olivine 25-27 wt%, jarosite 7-15 wt%, muscovite + orthoclase + oligoclase + albite 10-3 wt%, respectively. Magnetic measurements of the same particles also reveal very homogeneous amounts and grain sizes of magnetite. Such values are typical of the ones found in the most magnetic S-type spherules.

Spherules of the spherulitic aggregates have compositions similar to the Transantarctic Mountain cosmic spherules [1] and distinct from the Transantarctic Mountains microtektites [5] and from the glass shards found in Victoria Land tephra [6]. All spherules contain NiO, ranging from 0.66 wt% to 1.72 wt%.

Discussion: The chondritic bulk composition indicates that spherulitic aggregates are meteoritic in origin. The high concentrations of NiO in the spherule bulk compositions, in olivine and magnesioferrite, and the high MgO content and oxidation state of Fe in magnesioferrite (MgO = 11.7 ± 1.4 wt%; Fe^{3+}/Fe_{tot} =

86.6 ± 2.4) strongly indicate that the spherules constituting the aggregates are meteoritic ablation spheres[7].

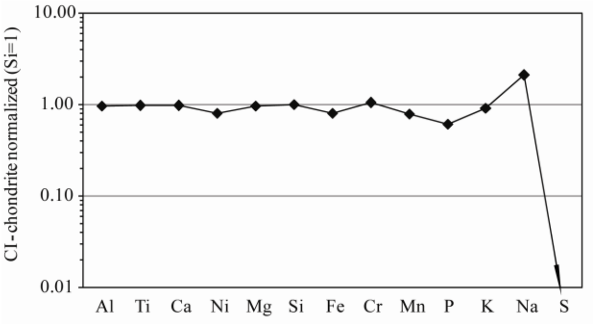

Fig. 2: Major element bulk composition of the spherulitic aggregates form the Transantarctic Mountain micrometeorite trap #20c at Miller Butte (Victoria Land, Antarctica) normalized to CI-chondrite bulk composition [8].

Furthermore, the bulk composition of the spherulitic aggregates is very similar to the bulk composition of the fusion crusts of chondritic meteorites [9]. Therefore, the spherulitic aggregates found at Miller Butte are ablation debris from a meteoroid of ordinary or carbonaceous chondritic parentage.

Two extraterrestrial dust-rich layers were recently discovered in the EPICA-Dome C and Dome Fuji East Antarctic ice sheet cores [10; 11]. The two layers have model ages of 431 ± 6 kyr and 481 ± 6 kyr, respectively. Remarkably, the ablation debris from Miller Butte are texturally and compositionally indistinguishable from the particles occurring in the 481 ± 6 kyr lower layer, indicating that they originated from a similar process. An age compatibility between the 1Myrs old micrometeorite trap and the 480kyr-old cosmic dust layer in EPICA-Dome C and Dome Fuji is observed. The unique characteristics of the ablation debris found at Miller Butte and that found in the EPICA-Dome C and Dome Fuji ice cores, coupled with their compatible age, thus suggest that they are most likely paired.

However, the likelihood that the ablation debris found at Miller Butte are paired with the ca. 480 kyr-old ablation debris found at Dome C and Dome Fuji, i.e. more than 2900 km apart, requires a plausible meteorite impact model able to produce a continental scale distribution of ablation debris. We estimate a minimal impactor mass of 10^8 kg, based on the nature of the impactor, the minimal extent of the distribution area (ca. 2.10^6 km^2) and the debris concentration determined at Dome C of 0.3 g m-2. Numerical simulations show that stony meteorites with masses in the 10^8 to 10^{11} kg range may undergo total disruption during atmospheric entry in the lower layers of the Earth's atmosphere, in a similar manner to the Tunguska event that occurred over Siberia in 1908 [12]. Modelling also show that at a later stage of a Tunguska-like impact a plume of hot vapour and ablation debris is created, which will ballistically expands at high altitude over areas extending for some thousands of km in radius, to then decelerate by gravity at lower altitudes producing a regional fallout of plume material [13]. We thus speculate that a plume similar to that modeled for the Tunguska event could have been responsible for the continental scale distribution of the ablation debris found at Miller Butte, Dome C and Dome Fuji.

Airburst events in the Tunguska-size class may occur globally with a frequency of 500-1000 yrs, with larger airburst events occurring on a 10^5 yr time frame [12]. Given this frequency, and the area of the stable ice sheet, we could expect to potentially record fallout from several Tunguska-like airburst events every 100 kyr in the Antarctic ice. Should the ablation debris found at Miller Butte prove to be a marker of Tunguska-like impacts, our detailed petrographic description will serve as useful guide for the search of such events in the geological record

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