COSMIC SPHERULES FROM THE NOVAYA ZEMLYA GLACIER SHEET: A TRANSMISSION ELECTRON MICROSCOPY STUDY OF THE TEXTURES

Badjukov D.D. (GEOKHI RAS), **Wirth R.** (GeoForschungsZentrum Potsdam),
Khisina N.R. (GEOKHI RAS)
badyukov@geokhi.ru; phone: (495) 939-70-70

Key words: *micrometeorites, cosmic spherules, crystallization*

Main mass of a cosmic matter fallen on the Earth is composed of particles of sub-millimeter sizes. The flux of the matter to the Earth is around 30 000 t/a [1]. The accreted material consists mostly of interplanetary dust particles that interact with the atmosphere and reach the Earth surface as micrometeorites (MMs). The MM accretion rate has been estimated to lie in a range from 2700 to 14000 t/a [2] and it overwhelms the meteorite flux which is approximately ~50 t/a [3]. It has been established that MMs are related to mostly carbonaceous chondrites [4]. It has been proposed that MMs might originate from comet nuclei [5]. On the other hand, asteroids have been considered as the main source of MMs [4].

Entering into the Earth atmosphere at velocities above 11.2km/s micrometeoroids interact with it in different ways. Some micrometeoroids are heated to low temperatures no more ~ 100ºC (unmelted MMs, UMMs), the others are converted to scoriae at temperatures of around 800ºC (scoriaceous MMs, SMMs) whereas the rest are totally melted (melted MMs or cosmic spherules - CS). Contents of CSs are from 30 % to 70 % in unbiased MM collections gathered at different sites and settings [2, 6, 7]. It should be noted that the observed low contents of CSs contradicts with results of numerical simulation of micrometeoroids interactions with the Earth atmosphere [4].

CSs are sub-divided into several groups according to their textures and c0hemistry. Barred olivine (BO) CSs (fig. 1a) are dominated among other groups and composed of clusters of parallel olivine crystals in glassy matrices with minor minerals like oxides and pyroxenes. It has been suggested [4] that they have been totally fused during atmospheric entry and lost by selective vaporization some fractions of volatile elements to Si. However, spindle-like spherules (fig. 1b) stand out among BO spherules. They sometimes contain separates of metal or ferrihydrite (fig. 1c). Also, some spherules have elevated contents of extraterrestrial water [5] and Na and K. Hence, we can propose that perhaps the spherules were delivered to the Earth like UMMs and have been melted during impact processes on their parent body.

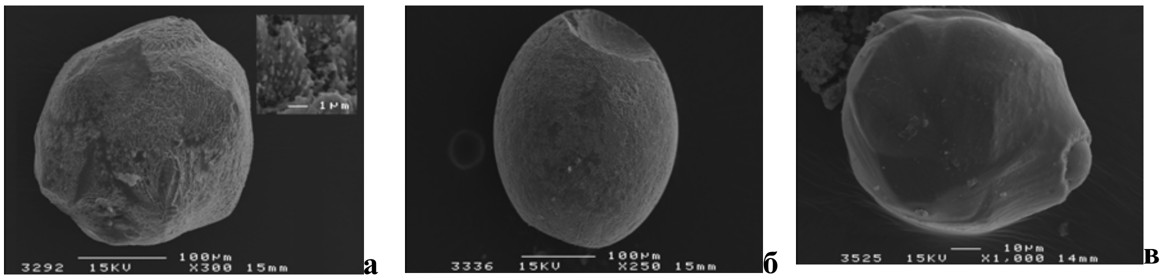
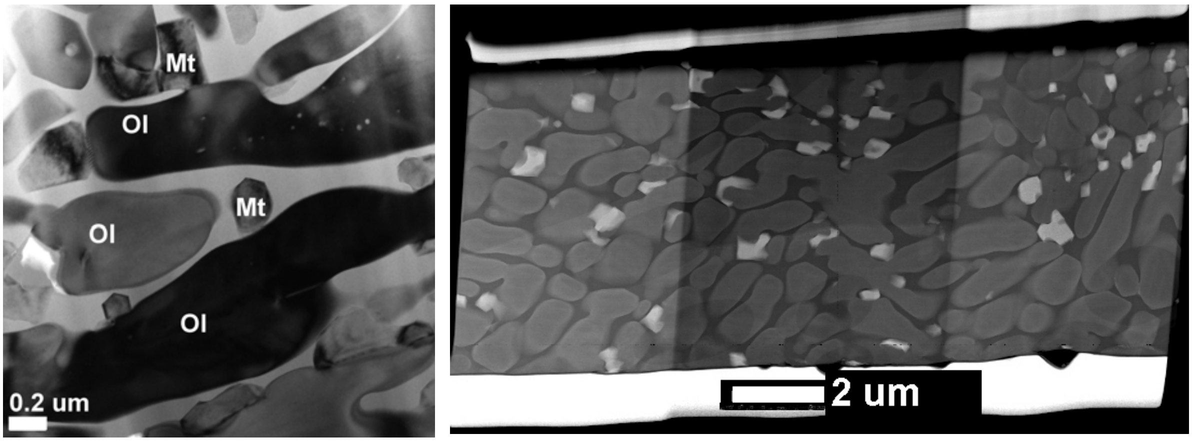


Fig.1. Scanning electron microscope imaged of BO spherules (SE). a- typical BO spherule; b – spindle-like Cs with a pit at the upper side; в – spindle-like CSs with a ferrihydrite sphere at the right side.

Here we report preliminary results of a TEM study of internal textures and phases of two CSs from the Novaya Zemlya MM collection for the purpose to recover the crystallization history.

Methods. For the study we used CS NZ8-bn4-25.7 that is a typical BO cosmic spherule and spindle-like CS NZ8-bn4-25.9. TEM foils were prepared from peripheral and central parts of the spheres using a focused ion gallium beam technique. The ~ 100 nm thick foils have the approximate dimensions 15 µm wide and 5 µm high. The foils were studied using a TEM equipped with an EDX HAADF detector.

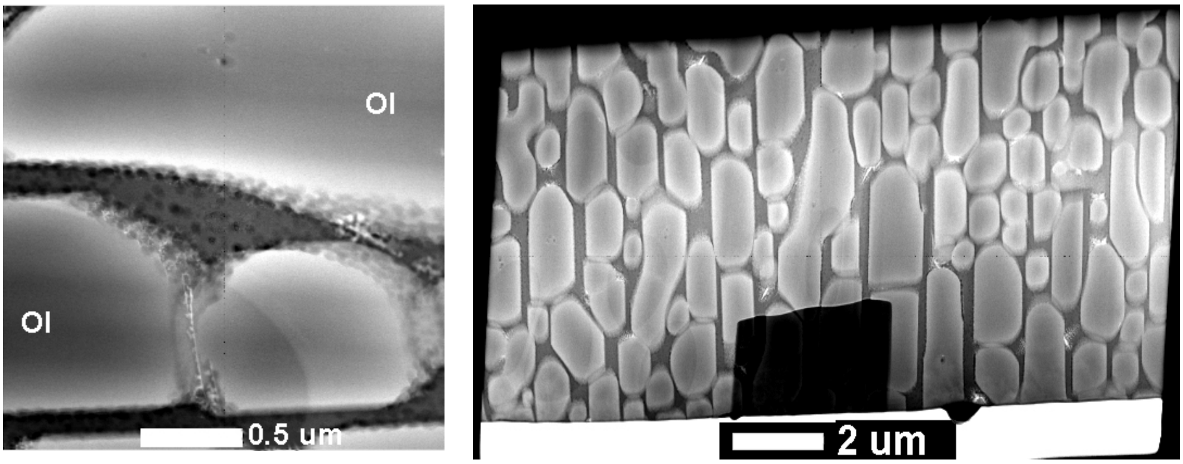
Results and discussion. CS is composed of rounded elongated crystals of olivine Fa_{20} of < 2 µm in size and euhedral Mg-Al-Si – containing magnetite crystals of < 0.5 µm in size that are embedded in a glassy matrix (fig. 2a). Matrix glass has 60 wt.% SiO_2, 12 % Al_2O_3, 11.5 % FeO, 3 % MgO и 13.5 %CaO with some Na_2O. Olivine was a first crystallized phase according to magnetite-olivine textural relationships. Basically, the texture of the CS is characterized by clusters of parallel olivine crystals oriented along [101] zone. Cluster sizes range from microns to tens microns; there is not correlation between crystallographic orientations of olivine crystals in adjacent clusters. The texture is distinguish from typical textures of BO chondrules in chondrite meteorites, the last is characterized by an olivine mantle and one or maximal a few dendrite olivine crystals developing from the mantle. Based on the observation we propose that crystallization of this sphere was homogeneous with formation of dendrite olivine crystals from crystallization nucleus. Terrestrial alteration is expressed as dissolution of olivine crystals at the very margin of the spherule.



a **b**

Fig.2. TEM images of a foil from a central part of CS NZ8-bn4-25.7 (a – bright field image, Ol – olivine, Mt - magnetite; b – film overview, HAADF detector)

CS NZ8-bn4-25.9 is composed of euhedral olivine crystals embedded in a glassy matrix. The glass has 45-60 wt.% SiO_2, 3.5-8 % Al_2O_3, 5-10% FeO, 27-31 % MgO, 5-6 % CaO. Simplectite chromite aggregates are present at contacts between olivine and glass. The glass has pores with diameters of tens nanometers (fig. 3a). Faces of olivine crystals have scalloped outlines that suggest a pore presence in the melt during growing of the crystals. The olivine crystals have strict orientation (fig. 3b) along plane (010).We suppose homogeneous olivine crystallization from overcooling melt.



a b

Fig.3. TEM images of a foil from a central part of CS NZ8-bn4-25.9, HAADF detector

Crystallization centers of olivine should be located parallel that might be due to molecular structural ordering in the overcooled melt.

Textures and mineralogy of the spherules show that they were totally melted that can be caused by the entering into the atmosphere. We modeled entering of 0.5 – 0.05 mm particles by velocities from 12 km/s to 30 km/s and different zenith angles. Maximal temperatures reach at 30 km/s velocity and are ~ 1800^o C (fig. 4a) that leads to total vaporization of particles by angles less than 50^o relative to a perpendicular direction to the Earth surface. Particles together with the heating experienced strong deceleration. The maximal apparent acceleration is around – 3000 g. The acceleration reaches hundreds of g by particle temperatures higher melting temperatures (fig. 4b) that has to lead to efficient separation of phases of different densities. However, the porosity of glass in CS

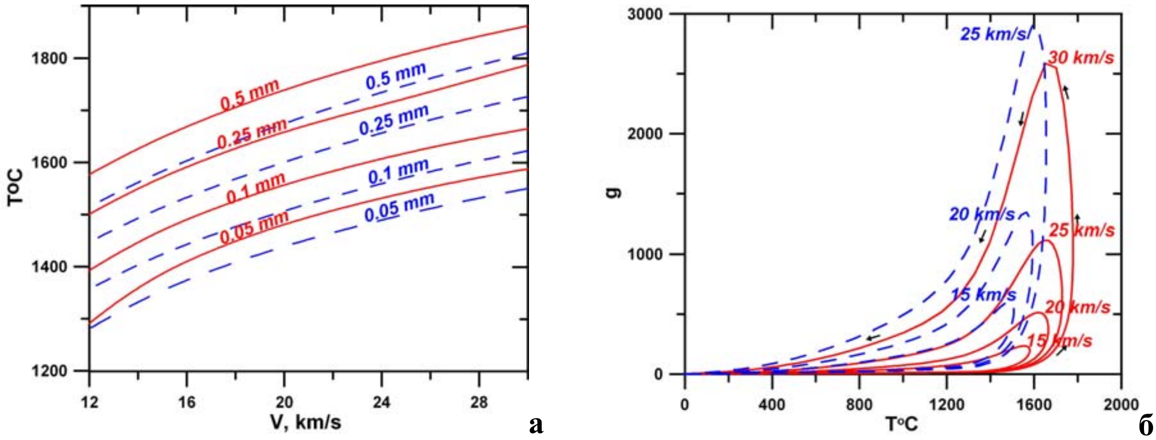


Fig.4. a – peak temperatures of particles of different radii for different entering velocities by entering angle of 60° relative to a perpendicular to the Earth surface and latent heats of evaporation to be $2*10^7$ kJ/kg (solid lines) and $5.7*10^7$ (dashed lines); б – apparent accelerations and temperatures for a particle of 0.5 mm in radius by the entering angle of 75° (solid lines) and 45° (dashed lines) calculated for the different initial velocities

NZ8-bn4-25.9 indicates that by crystallization the apparent acceleration has been very low if present. Hence, it can be speculated that a heat source for its melting was different from deceleration in the atmosphere and, as an example, can be due to an impact event by a collision of its precursor in space.

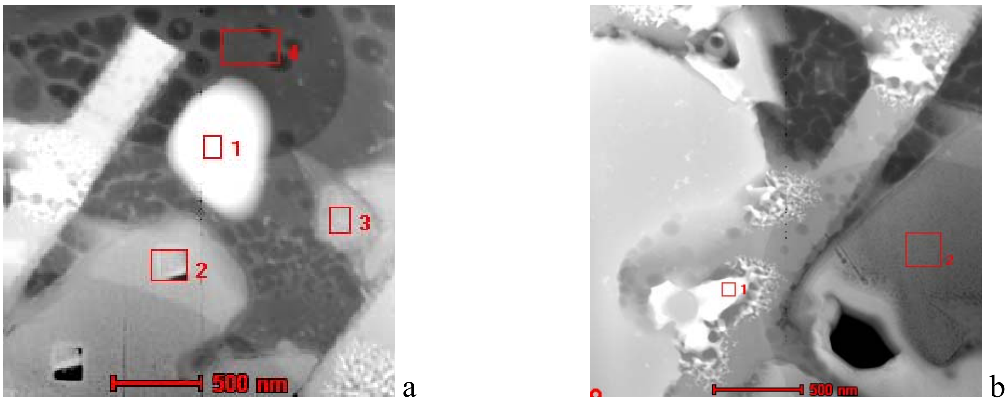


Fig.5. TEM images of foil from peripheral part of CS NZ8-bn4-25.9. HAADF detector. a. 1 – olivine, 2 – KCl, 3 – (K,Na)Cl, 4 – carbonaceous matter; b. 1 – chromite, 2 – KCl

Further, the spherule can be delivered to the Earth as other UMMs. Also, the spherule has very strange inclusions of KCl and NaCl with some Si, C, and O (fig 5, a,b) at the spherule periphery. We consider a contamination by sample preparation as very unlikely. Perhaps, the inclusions were formed either i) by a biological activity during terrestrial alteration or ii) by a capture of aerosol particles in the atmosphere or iii) by their formation in an impact plume.

The work was supported by RFBR grant (№ 09-05-00444) and grant ONZ-5 of Program of Earth Science Department of Russian Academy of Sciences

References

1. *Love S. G.; Brownlee D. E.* A direct measurement of the terrestrial mass accretion rate of cosmic dust // Science. 1993. 262. P. 550-553.

2. *Toru T. et al.* The global accretion rate of extraterrestrial materials in the last glacial period estimated from the abundance of micrometeorites in Antarctic glacier ice // Earth Planets Space. 2004. 56. P. 67-79.

3. *Halliday I. et al.* The flux of meteorites on the Earth's surface // Meteorites. 1989. 24. P. 173-178.

4. *Love S.G., Brownlee D.E.* Heating and thermal transformation of micrometeoroids entering the Earth's atmosphere // Icarus. 1991. 89. P. 26-43.

5. *Maurette M.* Micrometeorites and the Mysteries of Our Origins, Advances in Astrobiology and Biogeophysics // ISBN 3-540-25816-7. 2006. Springer.

6. Taylor S. et al. Types of micrometeorites accreting at the South Pole. Antarctica // 38th LPSC. 2007. # 1338 (abstract).

7. *Duprat J. et al.* Micrometeorites from Central Antarctic snow: The CONCORDIA collection // Advances in Space Research. 2007. 39. P. 605-611.

Electronic Scientific Information Journal "Vestnik Otdelenia nauk o Zemle RAN" № 1(27)'2009
ISSN 1819 – 6586
Informational Bulletin of the Annual Seminar of Experimental Mineralogy, Petrology and Geochemistry – 2009
URL: http://www.scgis.ru/russian/cp1251/h_dgggms/1-2009/informbul-1_2009/planet-7e.pdf

Published on July, 1, 2009