

Problems of Planetology, Cosmochemistry and Meteoritics

Barenbaum A.A. Origin of solar system comets (hypothesis review) cometoasteroidic concept UDC 550.2: 523.4-1/-8

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Abstract. A review of the known hypotheses of comets origin of Solar System is given. The author's concept is stated, according to which these comets arose in period from 5 to 0.7 million years ago and are the result of galactic comets collisions with bodies of the asteroid belt captured by the Sun into circumsolar orbits more distant than at asteroids. A theoretical model is constructed that adequately explains by this mechanism the main properties of long-period and short-period comets.

Keywords: *galactic comets; asteroid belt, long-period and short-period comets of Solar System.*

Introduction The observed comets, without exaggeration, can be attributed to the most amazing and mysterious objects of the Solar System. They represent huge of a few tens kilometers in diameter and up to $\sim 10^{18}$ g in weight “clods” of ice, dust and gases, mixed with rocky material, which move around the Sun in orbits that are a more diverse and distant, than for planets and asteroids.

Conditionally two main groups of such comets are distinguished: long-period – with periods of motion around the Sun $T > 200$ years, and short-period – with periods $T < 200$ years. The matter composition of both groups of comets is almost identical, but they differ sharply from each other in the nature of their trajectories. Comets of the first group have strongly elongated orbits with eccentricity $e \approx 1$, randomly oriented with respect to the Sun.

For the most part of their trajectory, comets are inaccessible to observations from Earth. However, when approaching the Sun at distances of less than 3–5 AU under the influence of solar radiation, comet ices evaporate, the comet nucleus is surrounded by a luminous shell (coma), and intense outflow of gas and dust begins from nucleus. From that moment on, the comet's brightness increases sharply, and it becomes discoverable.

As a result of multiple spans near Sun, comets lose their mass, and their glow decreases. After complete disappearance of glow in place of “dead” comet, meteor streams and small asteroids often detected which differ little from ordinary bodies of the asteroid belt. There are known cases of crushing and disintegration of cometary nuclei, as well as the falls of comets on planets and the Sun. Astronomers observe about 5 comets appearances annually, about half of which were previously unknown.

Today, many properties of observed comets have been explained and understood (Dobrovolsky, 1966; Vsekhsvyatsky, 1967; Kazimirschak-Polonskaya, 1978; Churyumov, 1980; Marochnik, 1985; Shulman, 1987; Tomanov, 1989; Marov, 1994; Tsitsin, 2009; etc.). And only the fundamental question about origin of comets themselves remains open, replete with a wide range of contradictory, often mutually exclusive judgments.

Hypotheses of comets origin in the Solar System

In accordance with the two varieties of comets, hypotheses of their origin are usually divided into two groups: “capture”, suggesting the capture of comets of galactic origin by the Sun, and “eruptive”, that imply comets birth in the Solar System.

The founder of the first idea is P. Laplace (1796), who believed that comets are interstellar objects that are gravitationally captured when approaching the Sun. The facts confirming this point of view were first presented by Svedstrup (1884), who discovered the connection between the perihelion of cometary orbits and the galactic plane. Later, this connection was confirmed and detailed by Oppenheim (1924), Lyttleton (1948), Vitkovsky (1971), Radzievsky and Tomanov (1973), Shorma & Khonna (1988) and others. The ideas about the galactic nature of comets in different years were developed by Bobrovnikoff (1929), McCrea (1953), Yabusita & Hasegawa (1978), Kazimirschak-Polonskaya (1978), etc.

The eruptive idea of the origin of comets belongs to P. Lagrange (1812), who was the first to suggest that comets could arise as a result of the ejection of matter by planets. Subsequently, this point of view was supported by Proctor (1881), who explained the origin of comets by strong volcanic activity on Jupiter, which took place 10 Ma. Drobyshevski (1978) and Guliev (1992) also adhered to this hypothesis. There are for many years, a consistent advocate of the idea of comets ejection during volcanic eruptions, not only of large planets, but also of their satellites, was Vsekhsvyatsky (1967).

A number of supporters of the eruptive hypothesis associate the formation of comets with the asteroid belt. In particular, Koval (1976) admits that the source of comets could be the bombardment by asteroids and meteorites of the icy surfaces of the giant planets satellites. Unlike him, Orlov (1936, 1960) believes that comets arise in the asteroid belt itself during collisions of its bodies. This point of view was shared by Fesenkov (1951, 1962) and supported by Radzievsky (1995).

In the middle of the last century, Oort (1950) proposed a hypothesis according to which the comets

origin is associated with the explosion of the planet Phaeton, which existed earlier, according to Olbers' assumption, at the site of the modern asteroid belt. The explosion of Phaethon, according to Oort, led to the ejection of many comets, which created a huge "comet cloud" on the Solar System outskirts. From this cometary reservoir, under the influence of various perturbations, comets come to the Sun today.

A year later, Oort (1951) abandons his original version and, following Schiaparelli (1871), Schmidt (1945) and Fesenkov (1951a), views the comet cloud as a remnant of a protosolar nebula. This idea was supported by Kuiper (1951), Safronov (1972), Epik (Öpik, 1975), Tsitsin et al. (1985).

However, this opinion is contradicted by the results of Van Flandern (1977, 1992), who, based on a detailed analysis of the orbital elements of 60 long-period comets, whose perihelion are in the asteroid belt, came to the conclusion about reality of the planet explosion between Mars and Jupiter, moreover only 3 Ma.

The listed hypotheses, like other ideas not mentioned (Vsekhsvyatsky, 1967; Churyumov, 1980; Tomanov, 1989; Marov, 1994) more or less fortunately explaining comets of one type, invariably experience difficulties in explaining the comets origin another type. For the capture hypotheses, these difficulties are associated with the complete absence of comets moving relative to the Sun along strongly hyperbolic trajectories, as well as with a very low probability of the capture of galactic comets by the Sun and with their subsequent transformation into short-period comets. For the hypotheses of eruptive type, on the contrary, difficulties arise in explaining the origin of long-period comets and their connection with the Galaxy plane.

The Oort comet cloud hypothesis is also not free from its shortcomings. In the case of the passage of the Sun through dense interstellar gas-dust clouds and as a result of close stars flight near the Sun, it must surely lose a significant part of its comets (Van den Bergh, 1982; Bailey, 1986; Dolgoplova and Marochnik, 1987; Chepurova and Shershkina, 1989). Attempts to move the cometary reservoir closer to the Sun (Whipple, 1964; Hills, 1982; Tsitsin, 1999, etc.) do not save the day.

The "cometoasteroidic" concept

In connection with the discovery of the phenomenon of jet outflow of gas and dust matter from center of our Galaxy and other spiral galaxies (Barenbaum, 2002, 2010) and creation of Galactocentric paradigm, the author proposed a new concept origin of observed comets based on Galactocentric paradigm. In accordance with this concept (Barenbaum, 1990), all comets, without exception, exist today in the Solar System, are daughter products of collisions of galactic comets

with bodies of asteroid belt, captured by the gravity of the Sun into more distant elliptical orbits than at bodies in the belt. Such "daughter" comets consist of a second time condensed matter of galactic comets, frozen together with debris and evaporated material of asteroids.

Due to double genesis of daughter comets, we cannot count them as objects of only eruptive or galactic origin and should consider them as a special category of bodies in the Solar System – "cometoasteroids".

According to the Galactocentric paradigm representations, cometoasteroids were formed in time interval from 5.0 to 0.7 Ma during period of the Sun stay in the Orion-Cygnus jet stream. Depending on size of acquired orbits, cometoasteroids are usually called long-period and short-period comets.

The former have aphelion of $\sim 10^4$ – 10^5 AU, as a result of which they return back to the Sun for the first time after ejection from asteroid belt. The composition of these bodies matter includes a significant part of galactic comets ice. When approaching the Sun, the ice intensively evaporates, and the outflow of gas and dust from them increases sharply. This fact, proceeding from existing cosmogony views, allows us to consider long-period comets as "youngest" objects of the Solar System, preserved unchanged from the moment of its formation.

Cometoasteroids of the second group revolve around the Sun with much shorter periods. They never left the Sun planetary system, have been made tens of thousands of revolutions around it, gravitate towards the ecliptic plane and could only survive in interplanetary space behind giant planets and between them. When they accidentally approach these planets, they are thrown towards the Sun, and then they are ranked as a family of short-period comets of corresponding giant planet.

The outlined cometoasteroidic concept of comets formation (Barenbaum, 1990, 1990a) was first voiced by the author in 1990 in Kiev at the "2-th Vsekhsvyatskikh Readings on the Physics and Dynamics of Comets", and then developed and theoretically substantiated in books (Barenbaum, 2002, 2010).

This concept postulates a close relationship between observed comets and other small bodies in the Solar System, primarily asteroids and cosmic dust. There is no fundamental difference between the comets of the Solar System and bodies of asteroid belt. The difference between these two groups of bodies is determined their orbits. The overwhelming majority of asteroids move within asteroid belt, localized at a distance from the Sun, where ice is sublimated by solar radiation. Whereas daughter comets, present outside this zone, keep ice in their composition for a longer time.

Cometoasteroidic concept also attaches great importance to relationship of observed comets with other processes in the Solar System, which are considered (Kuznetsov et al., 1991) as a complex of interrelated residual phenomena caused by recent presence of the Sun in galactic comets stream. Such phenomena include: the “peculiar” state of the Sun (Glushneva, 1994), increased geological activity of the Earth (Artyushkov, 1994), strong turbulence of giant planets atmosphere (Marov, 1981), the excited state of bodies in asteroid belt (Ruskol, 1986), significant dustiness of interplanetary space (Brownlee, 1984), as well as the presence in it of a large number of comets, meteorites, and asteroids with a dynamically short lifetime (Simonenko, 1985).

Conclusion

The main provisions of the cometoasteroidic concept of formation of the Solar System comets, based on ideas of the Galactocentric paradigm, are as follows (Barenbaum, 2010):

- Long-period and short-period comets there are secondary objects (cometoasteroids), captured by the Sun gravity and formed as a result of collision of the Galaxy comets (primary comets) with bodies of asteroid belt.
- The substance of both type comets consists of conglomerates formed by chemical and mechanical mixing of ice of frozen gases and dust of galactic comets with solid (debris) and diffuse (scattered and evaporated) material of asteroids.
- Short-period comets have never left planetary system of the Sun. As a result of repeated flights near the Sun, they have lost a significant part of their ice component. On the other hand, long-period comets have spent almost their entire life far from the Sun and retained this component. High concentration of aphelion of orbits of long-period comets at a distance of 10^4 – 10^5 AU from the Sun is a direct consequence of their formation and ejection from asteroid belt during last bombardment by galactic comets, which took place from ≈ 5.0 to 0.7 Ma, when the Sun was in the Orion-Cygnus jet stream of the Galaxy.

It should also be noted that the cometoasteroidic concept combines the best aspects of other known hypotheses of comets origin in the Solar System without repeating their shortcomings. It differs from “interstellar” hypotheses in that it does not cause difficulties in explaining origin of the comet families of giant planets. And off many “eruptive” hypotheses in that, that it easily explains the orbit features for various groups of long-period comets.

New concept preserves also the idea about presence in the Solar System a “cometary bodies

cloud”. However, unlike the hypotheses of J. Oort, D. Kuiper, I. Hills, F. Whipple, F. Tsitsin et al. this “cloud” consists of both comets and dust and gas, and is extremely non-stationary formation. It arises only in epochs of the Sun being in jet streams and spiral arms of the Galaxy and then exists for $\sim 10^6$ – 10^7 years. The total number of cometoasteroids in it at the present time, according to our estimate, is $\sim 10^7$.

And, finally, no less dignity of Cometoasteroidic concept is that it is an integral part of the general system of representations – Galactocentric paradigm, which connects the observed phenomena in the Solar System and on its planets with physical processes in the Galaxy, including formation of the Solar System itself.

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Ivanov A.A.¹, Sevastyanov V.S.¹, Shnykin B.A.¹, Krivenko A.P.¹, Dolgonosov A.A.¹, Laurinavichyus K.S.² Experimental model of abiogenic synthesis of high-molecular organic

compounds in conditions of early Earth UDC 550.47

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Abstract. The problem of abiogenesis acquires a new understanding if energy is added to the well-known functions of water. This function is determined by the disturbance of water masses and manifests itself in the form of a mechanical effect on the coastline zone, thereby facilitating synthesis of high-molecular organic compounds, as well as the processes of formation of prebiological structures from them. The presented results of experimental modeling of such processes satisfy the theoretical ideas about the presence of another important function of water - the function of energy supply to the structure-forming stage of abiogenic spontaneous generation of life.

Keywords: *abiogenic synthesis; energy format; caverns; structure-forming stage of abiogenesis; energy function of water; ultrasound.*

Introduction The question of the nature of the prebiological synthesis of high-molecular compounds and the formation of organic structures from them, necessary for the abiogenic spontaneous generation of life in the conditions of the early Earth, has no final solution today. This can be explained by the absence in research work of an acceptable natural source with an appropriate energy format. Such a source must meet the following minimum requirements:

- be present on the early Earth
- work in a cyclically acting mode
- must be efficient for a geologically long time
- have a sufficient but not excessive energy range
- be in close proximity to the place of energy consumption
- operate both in summer and in winter around the clock, i.e. regularly day and night
- the process of energy transmission should be soft: not destructive, short-term and local
- the ability to work simultaneously on land, at sea and in the primary atmosphere of the Earth.

Each of the above requirements is itself a separate problem of abiogenesis. This format does not correspond to any of the previously proposed energy sources, such as, for example, atmospheric lightning discharges, ultraviolet radiation and other radiation, meteorite strikes, volcanic and other geothermal activity of the planet. Therefore, they could not fully participate in the formation of prebiological structures, since neither individually, nor all taken together, fundamentally meet the above possibilities. At the same time, it was experimentally shown that these energy sources could support the synthesis of amino acids, nucleotides and other low molecular weight organic compounds. Although, in

general, it is clear that the unique conditions of the Earth were not required for this. Such simple organic compounds could also be introduced from the space environment. That cannot be said about their polymers, the formation of which required very specific prebiological conditions. We have already described the fulfillment of some of these requirements, with the participation of waves of the sea surf, in our previous works (Ivanov, 2020; Ivanov et al., 2020). These works reported on a new functionally possible role of the energy of water movement in the creation of polypeptide microspheres formed in the organic broth of caverns of abrasive shores, as well as on the role of the microspheres themselves in the formation of protobionts. Microspheres could be formed during thermocoagulation of peptides at the hot boundary of gas bubbles formed in caverns under the action of a pneumatic shock, which was initiated by the surf of sea waves. And we have shown this experimentally. In fact, the formation of polypeptide microspheres is a key moment in the beginning of the stage of structure formation of protobionts, since they, being in a multiphase water-bubble medium, changed in volume from a regular pressure drop during pneumatic impact. The constant pulsation of polypeptide microspheres in such an active environment forced them to primary metabolism, contributing to the qualitative transformation of the contents of their internal volume. This forced metabolism could serve as the basis for their evolutionary development. We have also shown experimentally that a pneumatic impact initiates the reaction of the formation of monosaccharides from formaldehyde, and with its participation an insignificant yield of peptides was obtained from amino acids. In this connection, given the high efficiency of pneumopercussion formation of polypeptide microspheres an effective process of replenishing peptides, as well as another high molecular weight organic substrate, was required, which in turn required additional energy costs. This idea contributed to the expansion of the search for studying the possibility of an alternative synthesis of these organic compounds, which led to a new direction of our research in the field of physics of abiogenesis processes, which were not given sufficient attention in previous works. These studies are associated with the further expansion of ideas about the energy function of water, and the experimental results show the reality of this possibility.

Experimental research model As well known, water plays a key role in the origin and development of life. However, when considering the problems of abiogenesis, as in many biological problems, it is generally accepted that water, as a rule, acts only as a universal solvent that performs a transport function.

In this work it is experimentally shown that water can perform one more function that was previously not considered for abiogenesis, and play a more significant role in the problem of energy supply for the entire process of abiogenic spontaneous generation of life. The essence of the experimental model lies in the fact that sea waves, when overturning on the coast and recoiling on the beaches, carry away myriads of grains of sand. In this case, ultrasonic vibrations occur in a wide frequency range - from units to hundreds of kilohertz (Bardyshev, 2008). Since it is known that ultrasonic vibrations affect the chemical interaction of substances, and are also capable of initiating cavitation processes, it was decided to investigate the possibility of experimental synthesis of high molecular weight organic compounds from simple amino acids using ultrasound. For this, the simplest amino acid - glycine, in the amount of 5 mg, was placed in a cuvette with 10 ml of water, and was exposed to ultrasound (100 W) for 4 minutes. In the experimental research model a generator with an ultrasound frequency of 20 kHz, of the UIP 1000hd type, was used. Before and after sonication, the solution was analyzed by mass spectrometry with laser desorption ionization in the presence of a matrix (MALDI - Matrix Assisted Laser Desorption / Ionisation) Bruker autoflex speed. The results of the experiment (Fig. 1) convincingly show the passage of organic synthesis, as a result of which, under the influence of ultrasound, a wide range of higher molecular weight organic compounds was formed from glycine. This experimental model of the beginning of the abiogenic synthesis of high molecular weight organic compounds under the conditions of the early Earth clearly shows the possibility of the participation of the energy of water movement in the process of abiogenic spontaneous generation of life.

Conclusion The question of the nature of the regularity of the synthesis of high molecular weight organic compounds in the conditions of the early Earth is one of the main ones in the problem of abiogenesis, since it is assumed that the first protobionts, and subsequently the first living organisms, were heterotrophs, i.e. consumed ready-made organic substrate for their activities. In this connection, the energy factor of providing abiogenic synthesis of high-molecular organic compounds in

the conditions of the early Earth is the key to understanding what, in fact, can predetermine the strategy of further search for new solutions to the problem. Along with the generally accepted role of water, we found a real probability of its highly efficient energy participation both in the processes of high-molecular synthesis of organic substances, and in the energy supply of the structure-forming stage of abiogenic spontaneous generation of life. Evaluating this function of water based on the results of experimental studies and comparing it with the energy format of other sources, it can be argued that today there is no full-fledged alternative with the requirements imposed for such a source. Thus, taking into account the new function of water, great opportunities open up for further studies of the previously proposed model of abiogenesis, in which caverns of abrasive shores are a probable place of spontaneous generation of life, where there is protection from hard cosmic radiation and an active medium, an influx of energy and inflow of organic matter.

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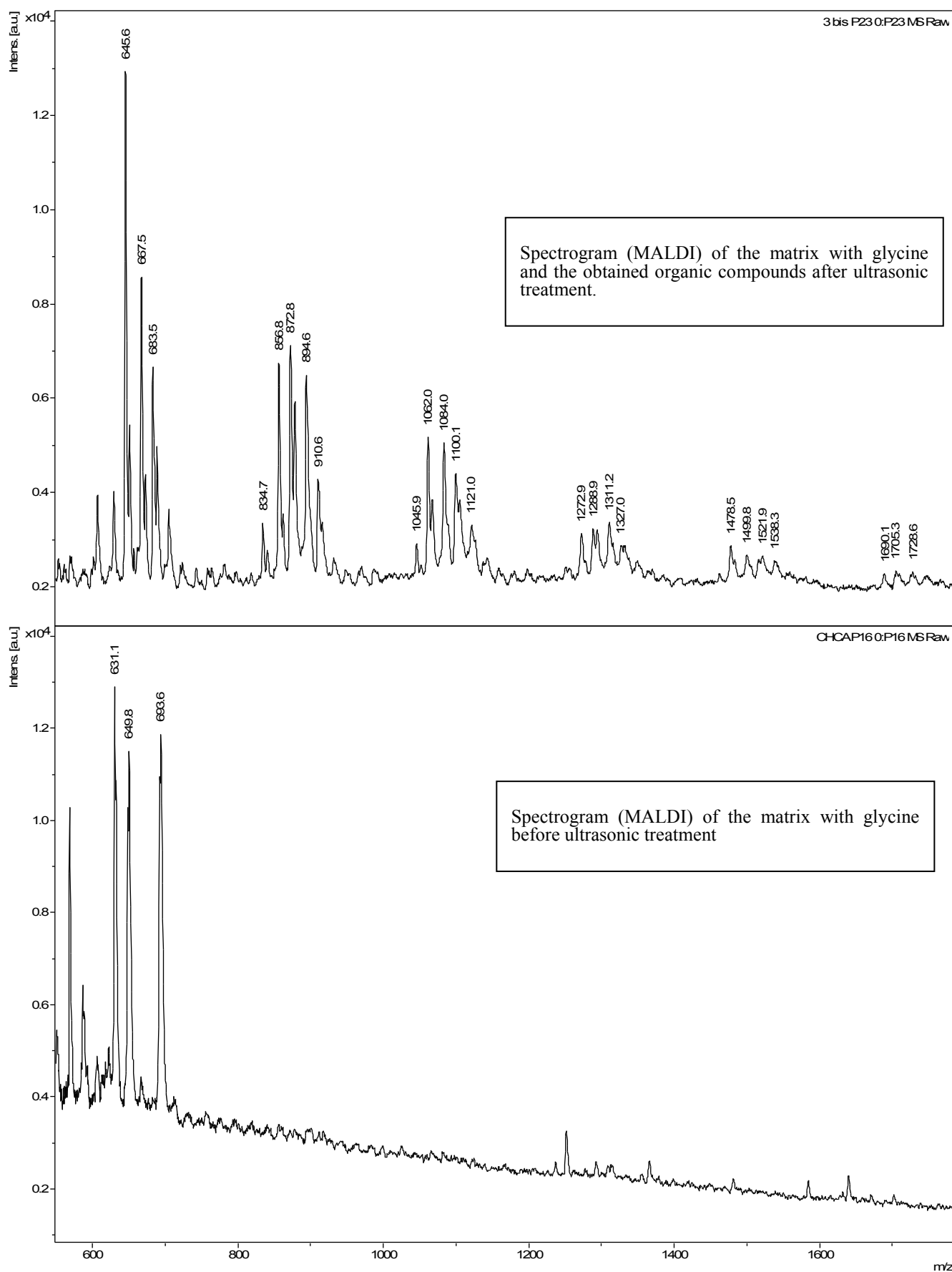


Fig. 1.

Kuyunko N.S. Thermoluminescent properties of equilibrium ordinary chondrites of various shock classes. UDC 550.42

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Abstract. The results of thermoluminescent studies of ordinary chondrites of various shock classes are presented. Measurements of natural and X-ray radiation induced in laboratory conditions thermoluminescence were made in the temperature range of 50-350°C. The thermoluminescence intensity was calculated relative to the Dhajala H3.8 chondrite. The maximum peak temperature of the thermoluminescent glow, peak's height and the area under the glow curve of the studied meteorites were determined. The obtained thermoluminescent characteristics were compared for meteorites that have experienced different degrees of shock load. The dependence of the height of the glow peak and the area under the thermoluminescent glow curve on the shock class of meteorites was found. The data obtained by X-ray irradiation of meteorite samples in laboratory conditions turned out to be more sensitive indicators of the degree of impact.

Key words: *thermoluminescence, ordinary chondrites, shock metamorphism.*

In the formation of meteorites, collision processes are assigned a determining role not only at the stage of formation of parent bodies, but also at the stage of their further existence as independent bodies. Shock-thermal metamorphism is considered as one of the fundamental processes of the evolution of extraterrestrial matter, and therefore it is important to find quantitative criteria for evaluating the effects of shock-thermal metamorphism. The thermoluminescent method is one of the simplest and most reliable methods for registering structural changes in a substance. It is widely used for the study of meteorites (Sears et al., 1980). There are two types of thermoluminescence (TL): natural (TLnat) – stored by a meteorite in outer space and induced (TLind) – induced in laboratory conditions from an external radioactive radiation source. TLnat measurements are used to estimate the orbits of meteorites (Melcher, 1981), shock-thermal history (Sears et al., 1980), identification of paired samples-finds (Benoit, Sears et al., 1991), etc. TLind reflects changes in the crystal structure of feldspar as a result of heat or impact, and therefore can be successfully used to study the metamorphism of ordinary and carbonaceous chondrites, as well as to study the shock-thermal history of meteorites (Alekseev et al., 2008, 2012).

In this investigation, the natural and X-ray radiation induced in laboratory conditions

thermoluminescence of equilibrium ordinary chondrites of various shock classes were measured.

For research, gross samples of meteorites weighing 0.7-1.0 g were crushed and crushed in a jasper mortar under a layer of ethyl alcohol. The magnetic fraction was separated with a hand magnet after drying for 24 hours in air. Three samples weighing 2 mg were prepared from the nonmagnetic fraction of each test sample by quartization method. Each sample was placed in a 6 mm diameter beryllium foil dish and evenly distributed on the bottom with an acetone drop under the binocular. The solvent was removed by air-drying for 24 hours. Thermoluminescence was recorded on a modified laboratory unit. The interface made on the basis of the L-154 board made it possible to register the photomultiplier current and the sample heating temperature on a computer. The resolution of the registration was 1°C. In this investigation the calculations of the parameters of thermoluminescence were carried out from the initial spectra. The average value of three measurements was used to calculate the thermoluminescence parameters.

Based on the results of registration of natural and X-ray induced in laboratory conditions thermoluminescence, the temperature of the maximum peak of the glow (T_{max}), its height (h), the area under the glow curve (S) and the intensity of the glow (TL_{nat} and TL_{ind}) were calculated. The thermoluminescence intensity was calculated relative to the Dhajala 3.8 chondrite. These thermoluminescent characteristics were compared for meteorites that have experienced different degrees of shock load obtained in the works (Stoffler et al., 1991) and (Dodd, Jarosewich, 1979). The dependence of the peak's height and the area under the glow curve of the thermoluminescence on the shock class of meteorites was found. However, the height of the glow peak and the area under the glow curve in the temperature range of 50-350°C, obtained by X-ray irradiation of meteorite samples in laboratory conditions, turned out to be more sensitive indicators of the degree of impact. The results of studies of X-ray induced thermoluminescence are presented in the table and in Figures 1-2. As follows from Fig. 2, when the shock pressure increases to 10 GPa (stages S1-S2), the values of the peak's height and the area under the glow curve (intensity of the thermoluminescence) increase, and then sharply decrease to two orders of magnitude with a further increase in the shock pressure from 10 to 90 GPa (stages S3-S5).

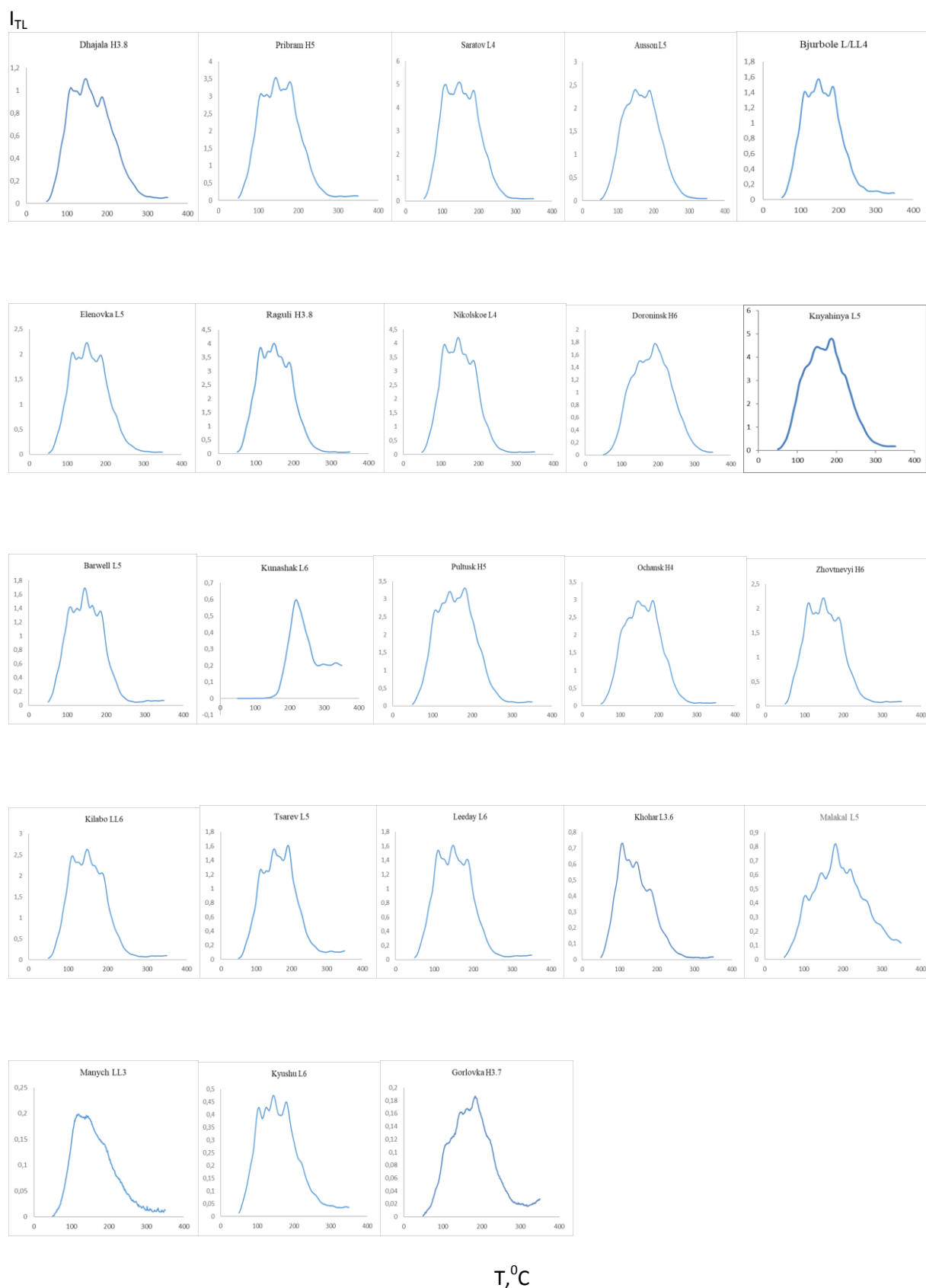


Fig. 1. X-ray induced in laboratory conditions thermoluminescence spectra of ordinary chondrites.

Table. Results of X-ray induced in laboratory conditions thermoluminescence of meteorite samples of various shock classes.

№	Meteorite	Shock class	Tmax, ⁰ C	h	S	TLind
1	Dhajala H3.8	S1	145	0,97	222	
2	Pribram H5	a-b	145	2,10	261	1,058
3	Saratov L4	S2	145	2,30	310	1,579
4	Ausson L5	S2	150	2,41	319	2,464
5	Bjurbole L/LL4	S1	150	2,50	326	1,303
6	Elenovka L5	S2	150	2,60	355	2,478
7	Raguli H3.8	S2	110	4,01	475	0,881
8	Nikolskoe L4	S2	145	5,20	671	3,492
9	Doroninsk H6	S2	190	5,96	809	1,867
10	Knyahinya LL5	S3	150	4,81	650	1,499
11	Barwell L5	S3	145	4,80	590	4,603
12	Kunashak L6	e	185	2,10	300	1,572
13	Pultusk H5	S3	180	2,30	285	1,017
14	Ochansk H4	S3	145	2,30	279	1,019
15	Zhovtnevyi H6	S3	150	2,21	266	1,657
16	Kilabo LL6	S3	150	2,30	262	2,184
17	Tsarev L5	S3	150	1,60	202	0,400
18	Leedey L6	S3	150	1,60	191	4,645
19	Khohar L3.6	S4	110	0,70	76	0,189
20	Malakal L5	e	180	0,27	45	0,288
21	Manych LL3	S4	120	0,19	25	0,058
22	Kyushu L6	S5	145	0,25	34	0,153
23	Gorlovka H3.7	S5	185	0,19	24	0,058

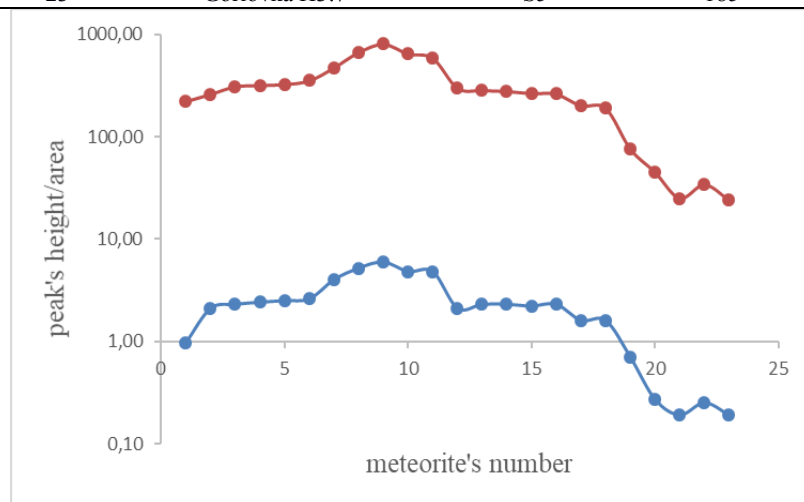


Fig. 2. The dependence of the peak's height (blue curve) and the area under of the thermoluminescent glow curve (red curve) on the meteorite's shock class.

laboratory conditions turned out to be more sensitive indicators of the degree of impact.

Conclusions. Measurements of natural and X-ray induced in laboratory conditions thermoluminescence in the temperature range of 50-350°C of ordinary chondrites of various shock classes were performed. The dependence of the peak's height and the area under the thermoluminescent glow curve on the shock class of meteorites was found. The data obtained by X-ray irradiation of meteorite samples in

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Lavrentjeva Z.A., Lyul A.Yu. The trace element studies of grain-sized fractions from ABEE EH4 unequilibrated enstatite chondrite. UDC 552.63

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Abstract. In the present paper the results of elemental abundances in separated grain-sized magnetic and nonmagnetic fractions from Abee EH4 enstatite chondrite are reported. It follows that the features of lithophile and siderophile trace element distributions probably result from crystallization from impact melts. The origin of such melts is probably to either in situ shock melting or incorporation of impact melt ejecta.

Keywords: *enstatite chondrites mineral fractions, trace element distributions.*

Mineralogical and isotopic data indicate that EC formed in a nebular region distinct from the other main belt asteroids possibly in the inner part of the solar system [Kallemeyn and Wasson, 1986; Shukolyukov and Lungmair, 1998]. Enstatite chondrites (EC) are thought to have formed in highly reducing environment. This inference is supported by the high Mg/(Mg + Fe) of olivine and pyroxene, presence of Si in Fe,Ni metal, and occurrence of typically lithophile elements, such as Ca, Mg, Mn and K, in sulfide minerals in enstatite chondrites [Weisberg et al., 2009]. Enstatite chondrites are divided into two main groups, EH and EL, based on high and low abundances of FeNi metal: both groups

show a metamorphic sequence from type 3 to 6, similar to that observed in ordinary chondrites [Baedeker and Wasson, 1975; Sears, 1980]. Abee is an impact – melt breccia, EH4 chondrite. This work reports data on the composition of separated grain-sized mineral fractions on the Abee EH4 enstatite chondrite which are considered from the viewpoint of cosmochemical history of EH chondrites.

Samples and methods. The fractions were selected by particle – size analysis and handpicking under microscope. The elemental composition of fractions was analyzed at the Central Laboratory of GEOKHI RAS using optimized version of neutron-activation analysis developed for analyzing extraterrestrial material (Kolesov et al., 2001).

Results and its discussion. The features of the microelement composition of the granulometric fractions isolated from the nonequilibrium enstatite chondrite Abee EH4 are considered. All grain-sized non-magnetic fractions (Fig. 1.) in the Abee meteorite are enriched in heavy REE relatively light [(Lu / La)_{fractions} / (Lu / La)_{CI}] = 1.2 - 3.0 and have both positive and negative Eu anomalies - [(Eu / Sm)_{fractions} / (Eu / Sm)_{CI}] = 0.7 - 1.4. Most of the rare earth elements were concentrated in nonmagnetic fractions with a grain size of 1 < d < 45 and 45 < d < 71 μm. Concentrators of rare earth elements are apparently accessory minerals, which are enriched in ultrafine fractions.

"Fine-grained" non-magnetic fractions (1 < d < 45 μm; 45 < d < 71 μm) (Fig. 1).

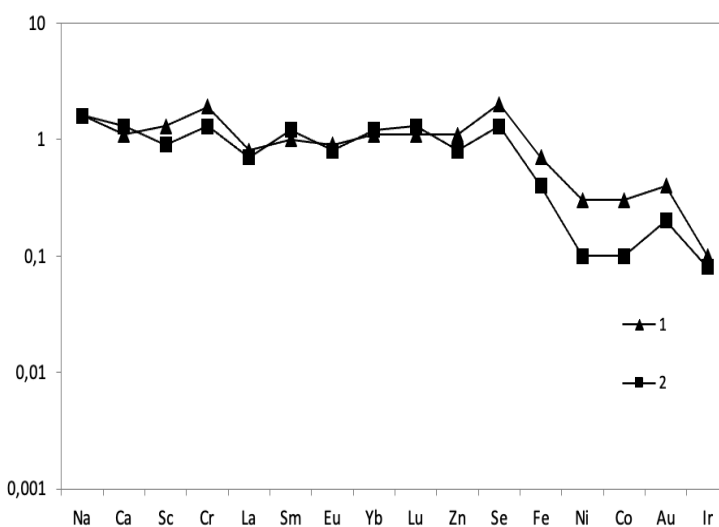


Fig.1. Normalized to CI chondrites the content of trace elements in non-magnetic "fine-grained" fractions isolated from the Abee enstatite chondrite: 1 - fraction (1 < d < 45 μm); 2 - fraction (45 < d < 71 μm);

Fine-grained non-magnetic fractions are enriched in lithophilic elements: Na (1.6 x CI); Ca (1.1 - 1.3); Sc (1.3 x CI); Cr (1.3 - 1.9 x CI); Sm (1.0-1.2 x CI); Yb (1.1 - 1.2 x CI); Lu (1.1-1.3 x CI); Se (1.3 - 2.0 x

CI); Zn ($1.1 \times \text{CI}$) and depleted in siderophilic Ni ($0.1 - 0.3 \times \text{CI}$); Co ($0.1 - 0.30 \times \text{CI}$); Au ($0.2 - 0.4 \times \text{CI}$), Ir ($0.08 - 0.1 \times \text{CI}$) elements. A characteristic feature of the distribution of trace elements in this fraction is the increased content of heavy REE relative to light $(\text{Lu} / \text{La})_{\text{Abee}} / (\text{Lu} / \text{La})_{\text{CI}} = 1.4 - 1.8$, with a negative Eu anomalies: $(\text{Eu} / \text{Sm})_{\text{fractions}} / (\text{Eu} / \text{Sm})_{\text{CI}} = 0.6 - 0.9$. The enrichment of fine-grained fractions of Na, Ca, Sc, Cr and REE with rare earth elements is possibly related to the fact that it contains accessory minerals - plagioclase and sulfides, which are the concentrator of many rare elements. Fine-

grained fractions differ from other size fractions by increased REE contents, which may also be due to the processes of evaporation and recondensation of fine-grained silicate particles in the matrix material as a result of shock processes. The volatile element Se ($2.0 \times \text{CI}$) shows a clear tendency to concentrate in the fine-grained fraction, which indicates the interaction of this fraction with the gas phase at a relatively low temperature.

"Mean-grained" non-magnetic fractions: $71 < d < 100 \mu\text{m}$; $100 < d < 160 \mu\text{m}$; $160 < d < 260 \mu\text{m}$ (Fig. 2).

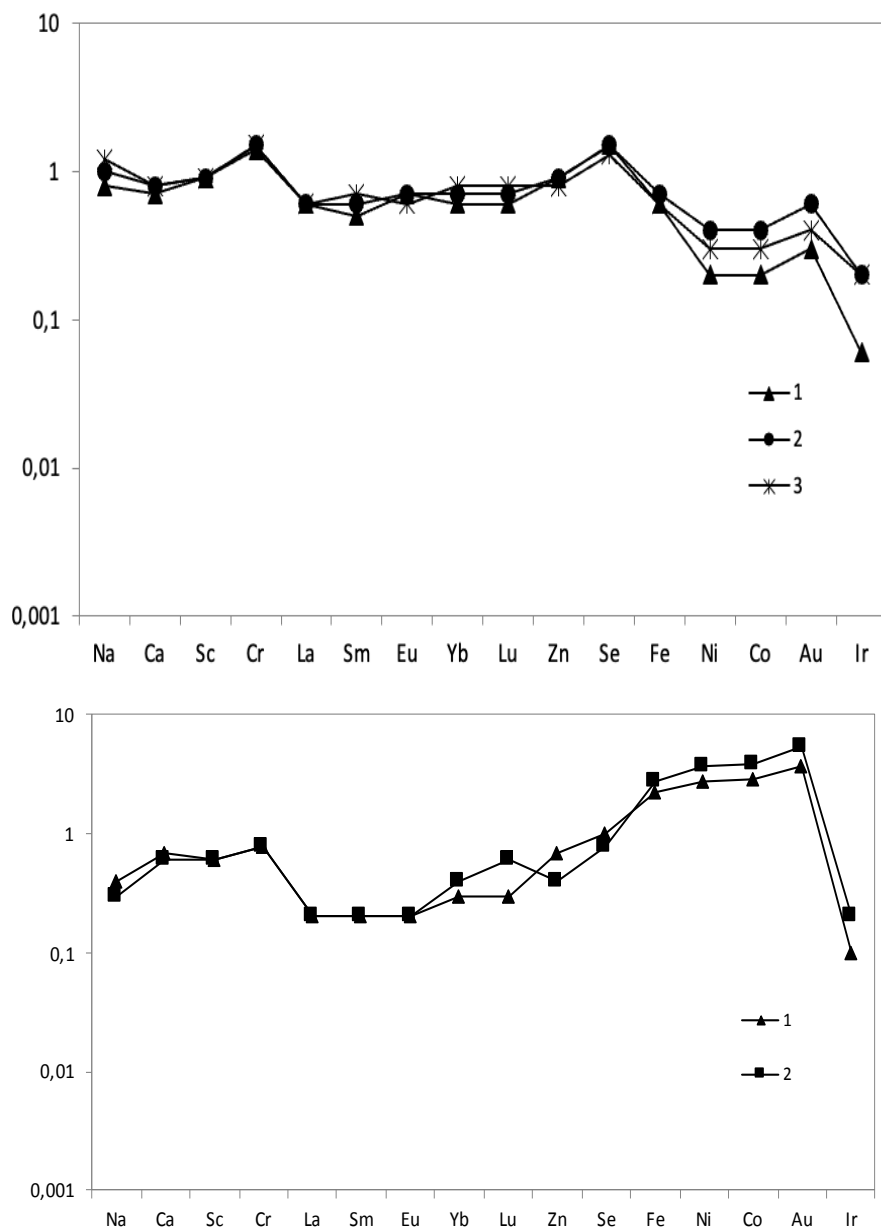


Fig. 2. Normalized to CI chondrites, the contents of trace elements in non-magnetic "mean-grained" fractions isolated from the Abee enstatite chondrite: 1 - fraction ($71 < d < 100 \mu\text{m}$); 2 - fraction ($100 < d < 160 \mu\text{m}$); 3 - fraction ($160 < d < 260 \mu\text{m}$).

Fig. 3. Normalized to CI chondrites the contents of trace elements in non-magnetic "coarse-grained" fractions isolated from the Abee enstatite chondrite: 1 - fraction ($260 < d < 360 \mu\text{m}$); 2 - fraction ($> 360 \mu\text{m}$).

"Mean-grained" fractions (Fig. 2) are depleted in refractory lithophilic elements: Ca ($0.6 - 0.8 \times \text{CI}$)

and Sc ($0.9 \times \text{CI}$), light and heavy and REE - La ($0.6 \times \text{CI}$); Sm ($0.5 - 0.7 \times \text{CI}$); Eu ($0.6 - 0.7 \times \text{CI}$); Yb (0.6

- 0.8 x CI); Lu (0.6 - 0.8 x CI) and enriched with non-refractory volatile Na (1.0 - 1.2 x CI) and non-volatile Cr (1.4 - 1.5 x CI). A characteristic feature of the distribution of trace elements in this fraction is the increased content of heavy REE relative to light (Lu / La)_{Abec} / (Lu / La)_{CI} = 1.0 - 1.3, with two positive and one negative Eu anomalies: (Eu / Sm)_{fractions} / (Eu / Sm)_{CI} = 1.2; 1.4; 0.8. It is possible that positive Eu anomalies in grain size fractions are associated with plagioclase and oldhamite. Close in average abundance values (0.2 - 0.6 x CI) for "normal" siderophilic elements Ni and Co and refractory Ir and non-refractory volatile Au are observed in all "mean-grained" fractions, indicating the absence of strong fractionation between siderophilic elements, which is typical for particles that have not undergone fractional crystallization. Such a prevalence of siderophilic elements allows us to make an assumption about the primary composition of the metal included in the silicates of these fractions. All medium-grained

fractions are enriched in the volatile element Se (1.3 - 1.5 x CI), which indicates a significant interaction of these fractions with the gas phase.

"Coarse-grained" non-magnetic fractions (260 < d < 360 μm; > 360 μm), (Fig. 3)

Unlike other fractions, in "coarse-grained" non-magnetic fractions (Fig. 3) there is a depletion in both volatile elements - Na (0.3 - 0.4 x CI); Zn (0.4 - 0.7 x CI); Se (0.8 x CI) and refractory lithophilic - Ca (0.6 - 0.7 x CI); Sc (0.6 x CI) and REE: La, Sm, Eu (0.2 x CI) and Yb (0.3 - 0.4 x CI) and Lu (0.3 - 0.6 x CI). When fractionating REE towards enrichment in heavy rare-earth elements - (Lu / La)_{Abec} / (Lu / La)_{CI} = 1.5 - 3.0, positive Eu anomalies are observed: (Eu / Sm)_{fractions} / (Eu / Sm)_{CI} = 1.0. In non-magnetic coarse-grained fractions, in comparison with other fractions, enrichment in all siderophilic elements is observed: Fe (2.2 - 2.8 x CI); Ni (2.8 - 3.7 x CI); Co (2.9-3.9 x CI); Au (3.7 - 5.4 x CI), except for Ir (0.1 - 0.2 x CI).

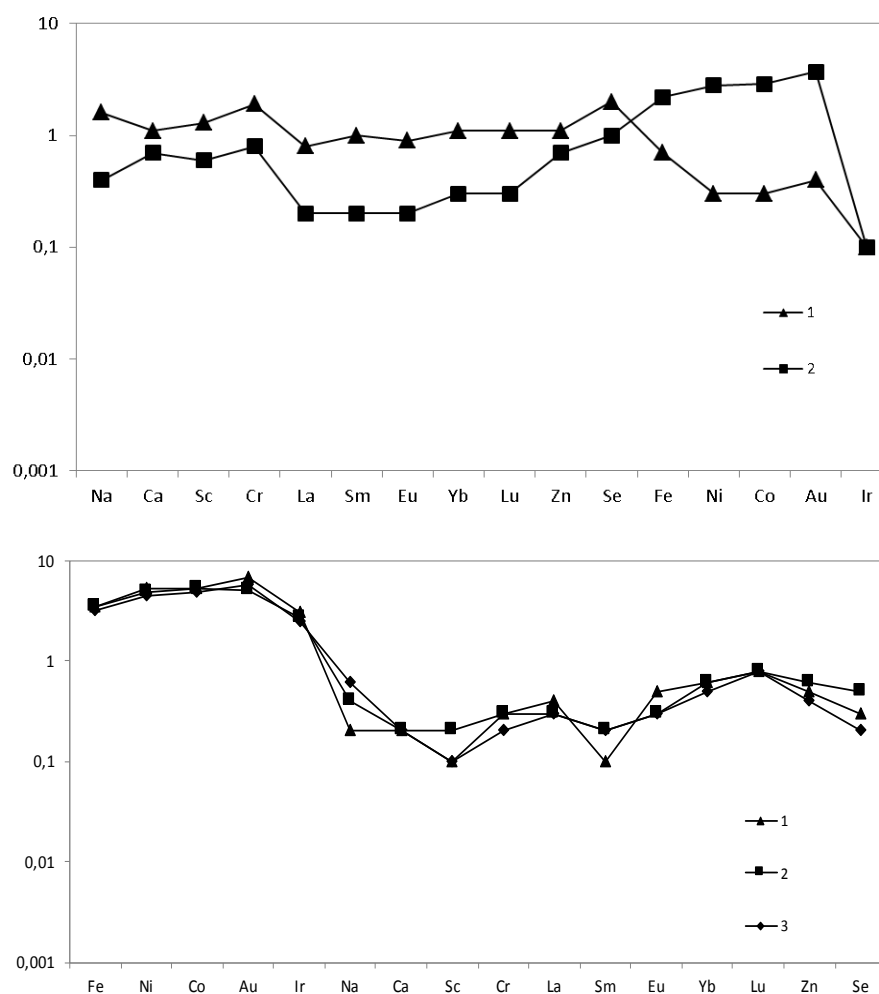


Fig.4. Normalized to CI chondrites the contents of trace elements in the non-magnetic "fine-grained" and "coarse-grained" fractions isolated from the Abec enstatite chondrite. 1 - fraction (1 < d < 45 μm); 2 - fraction (260 < d < 360 μm).

Fig. 5. Normalized to CI chondrites the contents of trace elements in magnetic "fine-grained" fractions isolated from the Abec enstatite chondrite: 1 - fraction (45 < d < 71 μm); 2 - fraction (71 < d < 100 μm); 3 - fraction (100 < d < 160 μm).

The following tendency is observed in the distributions of trace elements in the non-magnetic "fine-grained" and "coarse-grained" fractions: the "fine-grained" fraction is enriched in all lithophilic elements ($1.0 - 2.0 \times CI$) and depleted in all siderophilic elements ($0.1 - 0.7 \times CI$). The "coarse-grained" fraction, on the contrary, is depleted in all lithophilic elements ($0.2 - 0.8 \times CI$) and enriched in all siderophilic elements ($2.2 - 3.7 \times CI$), except for Ir ($0.1 \times CI$). In all nonmagnetic fractions, the ratio $(Ni / Co)_{Abee} / (Ni / Co)_{CI} = 1.0$. This distribution of siderophilic elements in the meteorite is possibly related to the presence of metal particles that have not undergone fractional crystallization. Variations in the ratio $(Ni / Ir)_{Abee} / (Ni / Ir)_{CI} = 1.3 - 18.5$; $(Ni / Au)_{Abee} / (Ni / Au)_{CI} = 0.5 - 0.8$; in the nonmagnetic fractions of Abee chondrite are possibly associated with strong fractionation of siderophilic elements. The strong fractionation of siderophilic elements in nonmagnetic fractions is also evidenced by the varying ratios $(Ir / Au)_{Abee} / (Ir / Au)_{CI} = 0.03 - 0.50$. In "fine-grained" fractions, this ratio varies from 0.25 to 0.40; in "mean-grained" - from 0.20 to 0.50; in "coarse-grained" fractions - from 0.03 to 0.04. The $(Ir / Au)_{Abee} / (Ir / Au)_{CI}$ ratios increase strictly with increasing grain size.

In magnetic fractions (Fig. 5) the ratio $(Ni / Co)_{Abee} / (Ni / Co)_{CI} = 0.92 - 0.98$; $(Ni / Au)_{Abee} / (Ni / Au)_{CI} = 0.76 - 0.98$; $(Ni / Ir)_{Abee} / (Ni / Ir)_{CI} = 1.79 - 1.81$ show that the composition of the metal differs from that in the non-magnetic fractions in the contents of Ir and Au. In all magnetic fractions, the Ir to Au ratio is lower than the cosmic ones and some variations are observed - $(Ir / Au)_{Abee} / (Ir / Au)_{CI} = 0.43 - 0.54$, which indicates the fractionation of these elements in the latter fractions, possibly as a result of metal remelting due to shock processes.

Conclusion. Based on the peculiarities of the distribution of siderophilic and lithophilic trace elements in the size fractions of the enstatite chondrite Abee EH4, it was assumed that the meteorite material underwent partial remelting due to shock processes, which were also the cause of brecciation. It is assumed that these features of the distribution of elements were acquired as a result of the crystallization of impact melts. The origin of such melts could be as a result of impact melting in situ or impact ejection of the melt.

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Mironov D.D., Grishakina E.A. Experimental studies of the lichen species xanthoria parietina, hypogymnia physodes and parmelia sulcata to daily temperature variations on the surface of Mars UDC 57.045

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Abstract. The understanding of organisms functioning is important in the question of the existence of life in Martian conditions. One of the most significant parameter, which the Earth organisms can't stand is large differences in daily temperatures due to the rarefied atmosphere.

Consequently, there is poor ability of the soil to retain heat. Lichens are quite resistant organisms to many environmental factors, including temperature variations too. In the experiment we imitate the conditions of a sharp drop in daily temperatures at the equator. Experiment was conducted by method of closed ecosystems. As a result we can see that not all used species can extinct. We suppose to use the results for the next astroecological and astrobiological researches.

Keywords: Mars; lichens; daily temperature variations; astrobiology; astroecology.

Lichens are known as the stress-tolerant organisms (Grime, 1979). Their high resistance to many extreme factors of environment is explained by morphological features and biochemical relationships between the photobiont and mycobiont. For example, lichens were able to survive in open space for two weeks (Young, 2005). During this time, they were exposed to extreme temperatures and high level of radiation. Lichens were also frozen in liquid nitrogen (Becket et al., 2008). Despite this amount of received knowledge and conducted experiments, there is not enough information about the resistance of lichens to large daily temperature drops that are observed on Mars. The understanding of high stress resistance of lichens can be assumed that they will be able to exist in the conditions of Mars.

Methods. The experiment was conducted by the method of closed ecosystems. During the experiment,

the temperature regimes of the Martian surface were simulated (Fig. 1, 2). There are can be the positive temperatures in equatorial latitudes on Mars and their value reaches + 25 ° C, but they hold for several hours and reached a maximum by midday. For

example, similar temperature regimes are observed in the next areas: Tiu Valley (0 ° N, 28 ° W); Great Sirte Plain (7 ° N, 280 ° W), Amazonian Plain (5 ° N, 160 ° W), Isis Plain (5 ° N, 289 ° W) etc.).

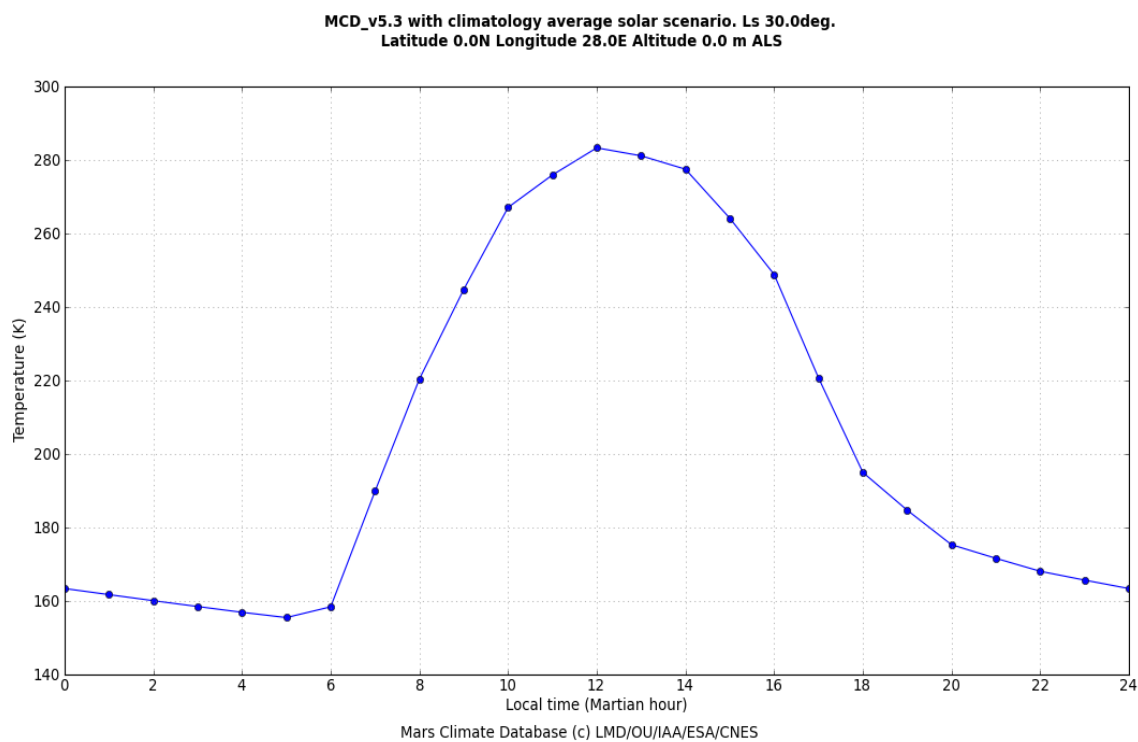


Fig. 1. Model of the temperature variation per day in the Tiuf valley at Ls 30 °, 0 ° lat. 28 ° W The model was built using the MCD database (François et al., 1999; Millour et al., 2018).

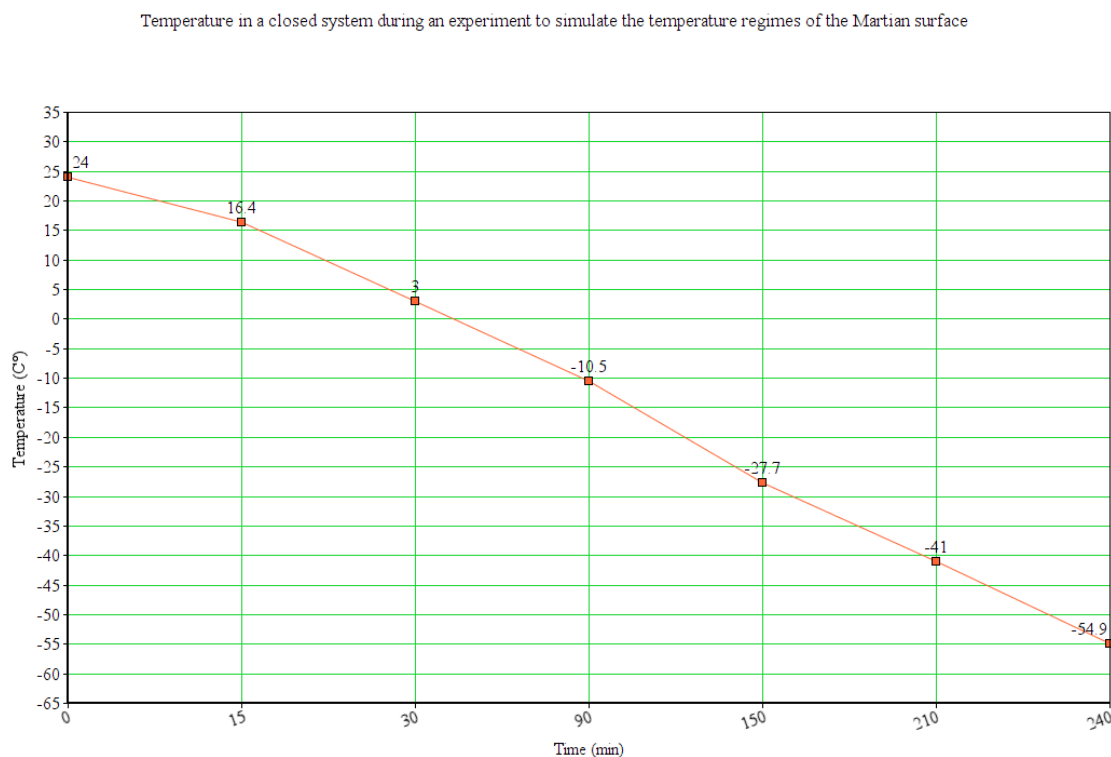


Fig. 2. Temperature in a closed system during an experiment to simulate the temperature regimes of the Martian surface.



Fig. 3. Closed ecosystems with test samples.



Fig. 4. Test samples on the first and second days of the experiment.

A cooling system for closed ecosystems was developed for this experiment. The closed systems and metal dish for receiving liquid nitrogen were placed in a wooden container. After the container was closed, the slots through which the evaporated nitrogen could theoretically escape were sealed with a sealed material. Then, through special holes on the lid, liquid nitrogen was fed into the metal dish for several hours, which, upon evaporation, cooled the internal environment of the container and closed ecosystems as well. Sensors were installed inside the ecosystems that recorded the temperature inside the closed ecosystem. The dashboard of the multimeter, which was used to record the temperature, was displayed outside the box, after which the indicators were recorded by the authors at a certain time. As part of the experiment, in order to comply with some realities, lichens were transplanted from their native substrate to a substrate that approximately imitates the Martian soil (Fig. 3).

Volcanic drainage produced by LLK «NadyaArte» was used as a substrate. Test samples were taken from the territory of the Danilovskoye Swamp nature reserve (Mironov and Muchnik, 2020).

When assessing the state of lichens, the morphological method of bioindication was used. This method is preferable for determining qualitative and quantitative changes at the organismal level. The formation of necrosis was noted on some of the test samples (Fig. 4).

In addition to studying the visible morphological changes, microchanges were also studied, which can only be seen with a microscope. To assess the state of the samples under study at the microscopic level, an MBS-9 microscope was used. Microscopic examination revealed microdamage to thalli on samples belonging to the species *Hypogimnia physodes* (Fig. 5). The noted microdamages were found in the areas of bending and twisting, where the thallus changed its sculpture, presumably under the influence of low temperatures.

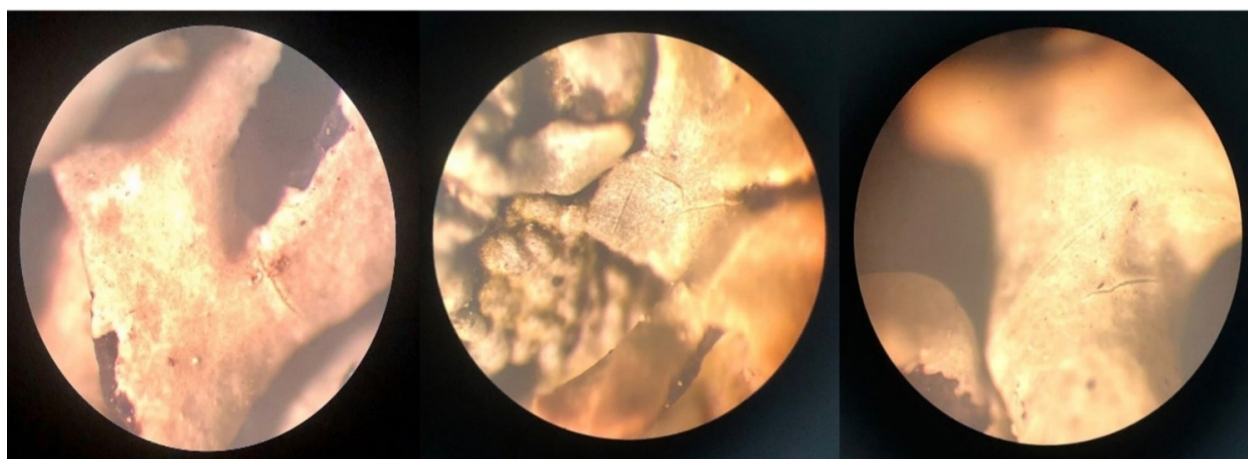


Fig. 5. Microdamages on thalli of *Hypogimnia physodes* specimens, made in the bases of bending and twisting.

Results. As a result of the experiment, the most resistant lichen species among the used ones were determined. There were no any morphological changes, including microchanges, on all the samples of *Xanthoria parietina*. Marginal thallus necrosis was found on two samples of *Hypogimnia physodes*. Most of the specimens were also subject to changes in the sculpture of the thallus surface, which manifested itself in the form of curling and bending of the edges of the thallus, and some specimens underwent twisting of the whole thallus. Under a microscope, in places where the sculpture of the thallus changes, microcracks and breaks in the thallus are found. 75% of the *Parmelia sulcata* population underwent complete necrosis, the remaining samples underwent significant (up to 20% of the thallus area) marginal necrosis. There is also a change in the sculpture of the thallus, which manifested itself in the form of its twisting. When examining samples of *Parmelia sulcata* under a microscope, no significant damage to the thallus was found. There were no any morphological changes, including microchanges, on all the samples of *Xanthoria parietina*.

Conclusion. *Xanthoria parietina* is the most resistant species among uses. It should be noted that due to the indicated and incomplete tightness of the structure and its deterioration, it is not fully simulate temperature conditions at the current stage, however, the experiment carried out allows the most accurate description of the behavior of the species used under simulated conditions. It is also worth considering that only temperature conditions were simulated in the experiment, and therefore, with the ecosystem approach, it is impossible to speak unambiguously about full resistance of certain organisms to the conditions of Mars. Study of other parameters and physical and geographical characteristics are planned for understanding the processes that can occur at the cellular level, as well as the biochemistry of the process, including examining samples using ecophysiological methods.

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Tselmovich V.A.¹, Maxe L.P. Comparative analysis of microstructure and composition of space-originated particles from trepel and desert sand UDC 523.681

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Abstract. A collection and database of magnetic microspheres (Mt-microspheres) and other space cosmic dust particles (CD) from the trepel of the field «Stalnoye» has been formed. To compare the morphology and composition of the Mt-microspheres from this collection, we selected CD-collectors with contrasting conditions, including the desert one (from the Kamil crater), which contains melting and oxidation particles from the traces of meteors, as well as from explosions over the desert surface. We compared the structure, morphology, and composition of Mt-microspheres in the collection «Stalnoye» with variants from the other collections, including desert sand, and drew analogies with the industrial technology of plasma chemical synthesis. The trepel as CD-collector contains several groups of microspheres that differ in the type of atmospheric plasma-chemical «treatment». The preservation of CD particles in the trepel is explained by the conditions of formation and accumulation of sedimentary matter in it. The «Stalnoye» collection represents a wide range of variations of CD particles, and, accordingly, the «Stalnoye» deposit field can be considered a preserving CD-collector that was accumulated CD for about 30 million years.

Keywords: *trepel, cosmic dust, Mt-microspheres, morphology, CD-collector, collection.*

Cosmic dust (CD), defined as micro- and nano-sized particles formed in space, is the main extraterrestrial component that increase the mass of the Earth. The mass profit of the Earth by the CD, in size part of which is related to micrometeorites, is much greater than the mass profit that gives meteorite bodies. In this regard, geological layers are often considered as a set of large information "CD-collector" (hereinafter referred to as CD-collector) that reflect the cosmic processes that have had a global impact on the Earth. The informativeness and value of the CD-collectors of the paleo deposits of the CD depends on the degree of preservation of the particles in them.

CD-collectors and collections of CD. A significant part of the CD is spherical particles ranging in size from several to tens and up to hundreds of micrometers. Informative CD-collectors that collect both the native CD and the products of

melting and combustion of meteor bodies in the atmosphere include deserts (the sands of the Sahara), ice (Antarctica), as well as sedimentary rocks formed before the beginning of man-made activity on the planet. In order to compare the morphology and composition of CD particles from the collection of the Stalnoye deposit, two CD-collectors with contrasting temperature conditions were selected: the desert one with a high temperature and the Antarctic one with a low temperature of CD particles in terrestrial conditions.

Italian scientists (Bignami et al., 2014) studied spherical particles, presumably of cosmogenic matter, that were extracted from sand which near the borders of the relatively young Kamil meteorite crater in the desert region of Egypt. The desert sands near the Kamil crater correspond to the criteria of CD-collector for the CD particles, so they have a certain information potential, especially taking into account the fact of the fall of an iron meteorite (on the border of Egypt and Sudan). The results of the research allowed authors to form a collection of spherical particles-micrometeorites and to identify the morphology of magnetic microspheres contained in the sands inside and outside the Kamil crater.

The many centuries-old ice of Antarctica is a unique CD-collector of CD that were fall to Earth in the past and is falling to the present. The authors of the Antarctic Ice investigation (Rojas et al., 2021) presented the results of a study of a collection of micrometeorites from the Antarctic CD-collector near Concordia Station (Antarctica). CD particles were separated from ultrapure ice by melting it, and 1,280 micrometeorites and 808 cosmic spheres with a diameter of 30 to 350 microns were identified. The measurement results were processed mathematically using programs and graphical image of the particle size and mass fraction distribution. The authors believe that the total mass of CD coming to the atmosphere before entering it, is about 15,000 tons per year, and the mass of CD falling out, according to the new data, is estimated about 5200 tons per year. Presented by the authors (Rojas et al., 2021), the results and conclusions of the study of the Antarctic ice CD-collector relate to the determination of the nature of the distribution by mass and size of the falling down particles of the CD.

The discovery of a place over which a meteorite exploded in the air in Antarctica, the collection of material from a CD-collector and its study made it possible for other authors (Ginneken et al., 2021) to obtain large CD particles with a distinctive morphology. After studying the products of melting and condensation of the meteorite substance, the authors put forward their own theory and they point out that not all meteorite explosive events left craters on the Earth's surface. The authors (Ginneken et al., 2021) believe that it is necessary to look for CD

particles in marine sediments, which also were accumulate microspheres formed during air explosions of meteorites above the water surface.

Sedimentary rock – trepel as CD-collector. Earlier, we (Tselmovich et al., 2020) showed the presence of Mt-microspheres in the trepel of the Stalnoye deposit (Republic of Belarus, Mogilev region, Khotimsky district). The large number of big and clean magnetic spheres found in trepel, which are not damaged by terrestrial processes, suggests that some stratigraphic level is enriched with CD particles. A collection of Mt-microspheres and other CD particles was formed, as well as a collection database (SEM images, elemental composition, etc.). Trepel of the Stalnoye deposit is a natural composite polymineral, in which are dominated smectites and zeolites with the presence of up to 25 % of the carbonate component (in the form of calcite).

The classifications of micrometeorites. Based on own collections and data the classifications of CD particles that have reached the Earth are proposed by authors and teams from different countries. A reasonable petrological-chemical classification of micrometeorites was proposed by a team of authors (Genge et al., 2008), based their classification on the analysis of data from several thousand micrometeorites collected in the Antarctic ice. Genge and co-authors believe that some distinctive features of the particle morphology allow them to be assigned to a specific group of micrometeorites without or before isotopic analysis. Depending on the degree of thermal processing at penetration into the atmosphere, they subdivided micrometeorites into several groups. The authors (Genge et al., 2008) emphasize that the changes caused by atmospheric heating have the character of degradation, and these processes and composition of particles have become criteria for the classification of micrometeorites.

Analyzing the structure and morphology, taking into account the significant transformations of cosmogenic matter in the Earth's atmosphere, a model of its evolution was presented by Russian Far Eastern scientists (Savelyeva et al., 2020). They considered various variants of the origin of spherical particles, predicting possible collections, origin, composition, structure and morphology of spherical particles, proposed and presented a model of the behavior of a cosmogenic particle in the Earth's atmosphere.

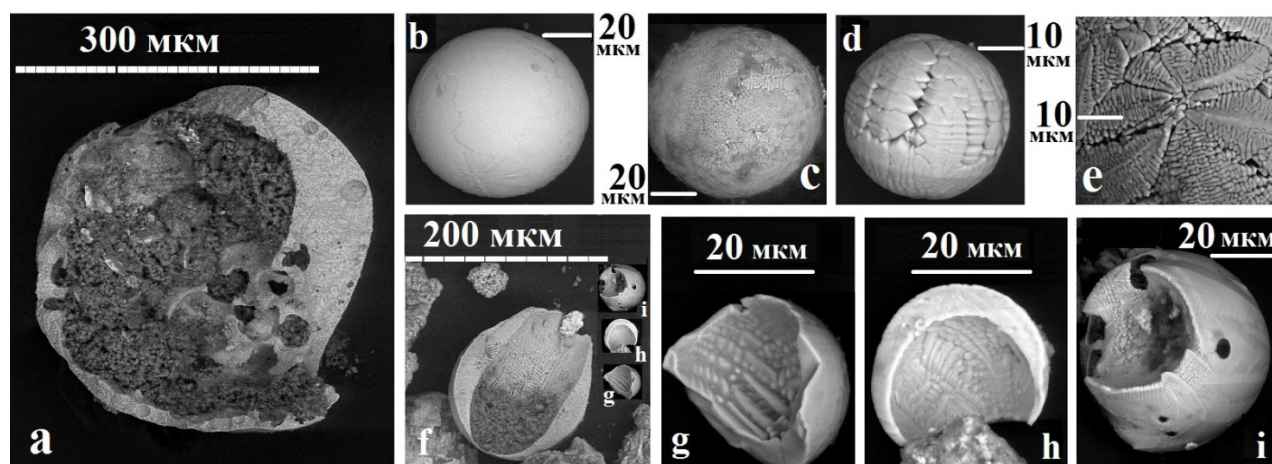
Comparative analysis of magnetic microspheres from trepel and other CD-collectors. We chose the most discussed variants of the formation of magnetic cosmogenic microspheres as the basic ones for comparison. The first variant is Mt-spheres that have fallen into the water. These are, initially, mainly large iron particles of CD (hundreds of micrometers), they very quickly (in about 5 seconds) fly through the atmosphere, warming up to

melting, have time to oxidize, crystallize, and fall to the bottom. The second variant is Mt-spheres, which were formed during the complete combustion of meteor bodies and became plumes-placers of CD in the ice. The third variant is explosion, in this case, partially Mt-spheres could form, fused in two, three or even larger formations, fall down into the ice, were well preserved, without being destroyed. The fourth variant is Mt-spheres, similar to the collection of spheres found in the desert sands (in the Kamil crater), which can have a mixed character, including both melting and oxidation particles from the traces of meteors, and particles formed by the explosions of meteor bodies in the air above the desert surface.

Using SEM images, we compared the structure, morphology, and composition of Mt-microspheres in the collection of particles isolated from the CD-collector of the Stalnoye deposit with the above-mentioned variants. Due to the method of separation used by forming of the "Stalnoye" collection, in this are no microspheres with a significant silicate component. In the "Stalnoye" collection, there are large (more than 250 microns) and medium-sized Mt-microspheres (100 – 250 microns) with a pronounced dendritic surface structure, as well as with zonal or mixed. Some medium and small Mt-microspheres (less than 100 microns) have a zonal crystal surface. At the same time, in the "Stalnoye" collection, we identified ablative Mt-microspheres, both small and medium in size. The "Stalnoye" collection also revealed the presence of split Mt-microspheres, hollow inside, with a pronounced asymmetry of the Mt-shell and traces of the flow of

magnetically swirled melt on the inner surface. In the large particle fraction of the "Stalnoye" collection, there are Mt-microspheres fused from two and three separate spheres. Among the Mt-microspheres of the "Stalnoye" collection, there are those damaged by micro explosion – these are spheres with holes similar to the "exhaust", and not a shrinkage cavity. The insides of such explosion-damaged Mt-microspheres are filled with products resembling slag or bio-damage (in the case of dry particle separation). In the "Stalnoye" collection, there are no microspheres similar to "shot" of Fe-Ni, but ribbon and thread-like particles of Ni and alloys are found.

The inner part of dendritic Mt-microspheres resembles shrinkable sinks, which are formed during the crystallization of metals and alloys. At the same time, there are dips inside the spheres and thin-walled ablative Mt microspheres with loose contents inside (slag, bio-damage). Because the CD particles of different sizes and shapes enter the atmosphere from space, if they are larger than 50 microns in size, they heat up, melt, oxidize, crystallize, fall into the CD-collectors, and then can get into the CD collection. True cosmogenic CD particles – the smallest (less than 50 microns without taking into account the ice shell) they overcome the atmosphere relatively calmly and, for a while, become part of atmospheric aerosols. In the "Stalnoye" collection, there is still a little-studied fraction of Mt-microspheres with minimal dimensions. We assume that this micro-dimensional CD is partially lost during the separation of Mt-microspheres, as well as and the non-magnetic component of the CD lost.



SEM VEGA\TESCAN GO «Borok» IPE RAS

Fig.1. Mt-microspheres from the "Stalnoye" collection: a – large split sphere with inclusions; b – split sphere with "exhaust"; c – damaged semisphere with traces of melt flow; d – semisphere with wall thickness asymmetry; e – sphere with asymmetric "exhaust"; f – ablation sphere; g – sphere with mixed structure; h – sphere with dendritic structure; i – fragment of the surface of a large sphere with dendritic structure.

Plasma chemical synthesis in the atmosphere, preservation at the bottom. Analyzing the

structures and morphology of Mt-microspheres from the "Stalnoye" collection and desert sand, we drew

analogies with the industrial technology of plasma chemical synthesis. During the plasma-chemical process in the Earth's atmosphere, from the body of the meteor, from the most incandescent – molten zone, are separated, and in fact cut off, by parts – drops of melt, then follow supercooling and crystallization. In a drop, both thermal supercooling with a heat sink and concentration supercooling can occur simultaneously, which redistributes impurities in the solid and liquid phases, creating layers or areas with an excess impurity content. If the impurity has a lower crystallization temperature, it is displaced or "shot". As the drop moves away from the source with a high temperature (the plasma region) it undergoes thermal supercooling, and the crystallization rate increases. The crystallization of magnetite in a drop occurs after a strong overheating of the melt (and metal oxidation), but very quickly. In the remaining part of the meteor body, the supercooling of the intermediate layer (under the plasma) causes the formation of drop-spheres or chondrules, which can't tear themselves away without additional heat supply, some of them remain in the melted crust and are visible in it.

The big concentrating supercooling (high concentration of impurities, sufficient layer width) and slow crystallization rate (at a low temperature gradient) create conditions for the formation of a dendritic structure. With a small concentration supercooling, an insignificant content of impurities, but the presence of a large temperature gradient, a cellular structure is formed. Intermediate variants lead to the formation of mixed structures - zonal-dendritic. Primary zonal-dendritic and zonal structures have a higher density of "laying" and greater strength, and potentially - undamaging. An increase in the crystallization rate and, accordingly, the degree of dispersion of the primary structure (a decrease in the width of the axes of cells and their boundary zones, the width of the axes of dendrites and the distance between them) affects the mechanical properties – improves strength, make better preservation.

Thus, several groups of microspheres are collected in the trepel CD-collector of the Stalnoye deposit, which differ in the type of atmospheric plasma-chemical "processing". Some were formed by meteors that in the atmosphere were burning up, others – by explosions of meteor bodies, and still others – from open space that have overcome the atmosphere, preserving or slightly changing their composition, morphology, and structure. The preservation of CD particles in the sedimentary rock – trepel is explained by the conditions of formation and accumulation of sedimentary matter in deposit. Chemical "preservation" was ensured by the almost constant presence of bottom gel of silica, from which aluminosilicates – clays, zeolites-were formed. At the

same time, the conservation of CD in the sediment at the bottom was facilitated by the biota of the ancient sea, which left coccolites, diatomaceous shells, radiolarians, and mineralized algae in the trepel.

Conclusions. In the collection of micrometeorites – Mt-microspheres extracted from the trepel of the Stalnoye deposit, spheres with a dendritic, zonal mixed structure, ablative, fused with each other Mt-microspheres, as well as microspheres with traces of the "exhaust" of the core to the outside were found. The "Stalnoye" collection represents a wide range of CD particles belonging to various classifications and groups, respectively, the Stalnoye deposit can be considered a preserving CD-collector of CD that have accumulating for about 30 million years. When comparing the CD particles from the various CD-collectors such as trepel, desert, and Antarctica, the morphology and composition largely coincide, which indicates a single cosmogenic mechanism of their origin.

A targeted study of the stratigraphic levels of the Stalnoye deposit will provide an opportunity to obtain important scientific information, to obtain a complete background and private (by level) collections of CD particles for a long geochronological period of the Earth.

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Yakovlev O. I., Shornikov S. I. Experimental data of alkali component evaporation from chondrule melts

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Abstract. Geochemical problem of K and Na evaporation is a key one when deciphering physical and chemical origin conditions of chondrule melts of chondrites. Experimental data on K_2O and Na_2O evaporation from melts with diverse SiO_2 contents showed that the evaporation process depends clearly on acid-basic melt properties. Observed dependence is interpreted within the framework of the D. S. Korzhinsky's theory of acid-basic component interaction in the silicate melts. Examples of evaporation of the model compositions similar to chondrule compositions confirmed the main theoretical ideas that basic parameters of component activity – concentration and coefficient activity – control K_2O and Na_2O behaviors.

Keywords: *chondrules, evaporation, components activities, theory of acid-basic component interaction*

This paper discusses the evaporation of potassium and sodium from chondrule melts that is important for the chondrule formation process. In meteoritics, this issue is receiving increased attention by researchers. It is believed that the study of the alkali evaporation will provide a key to understanding the physicochemical conditions for the chondrule formation. Despite the recent advances in experimental studies on the melt evaporation, it should still be admitted that the conditions of the alkaline component evaporation from chondrule melts remain "mysterious" (Ebel et al., 2018). For example, it was known that potassium in elementary, oxide, chloride, and in many other simple forms is more volatile than sodium. The same regularity was observed in experiments on the evaporation of basaltic and more basic melts (Yakovlev et al., 1973; Kreutzberger et al., 1986; Ustunisik et al., 2014). However, most authors studying the chondrule evaporation, report different and even opposite opinions, supported by experimental data. For example, Yu et al. (2003) reported that potassium and sodium are similar in their behavior at evaporation. For chondrite and chondrule melts, it is obvious that Na evaporates faster than K until the sodium content reaches low values. The idea of high sodium volatility gave motivation to some leading researchers of chondrules to argue that the sodium content in chondrules mostly restricts the conditions of the chondrule formation (Ebel et al., 2018). Thus, the ideas of the comparative volatility of potassium and sodium are different. Some assumptions were

made to explain the reasons for this contradiction (Yu et al., 2003; Ebel et al., 2018). For example, Yu et al. (2003) indicated the fact that large evaporative losses of sodium were observed in a less polymerized melt, that means, in the melt with a lower silica content. The similar regularity was observed for potassium. Summarizing the data of the experiment on the potassium and sodium evaporation, the authors suggested that the reasons for the contradictory behavior of the alkaline components should be sought in the differences in their activities, or, more precisely, in the differences in their activity coefficients in different melts. In our opinion, the authors assumption provides the right direction for studying of the problem of comparative evaporation of alkalis from the chondrule melts.

The relative volatility of potassium and sodium from the melt at evaporation were studied 50 year ago in detail by Yakovlev et al. (1973), and it was shown that the activity coefficients of Na_2O and K_2O are indeed important factors determining the evaporation process. Here, we present experimental data on the evaporation of K_2O and Na_2O from acid-contrasting melts – basalt and granite. The experiments were carried out in a vacuum chamber at 1180–1450 °C, at pressure of 10^{-9} bar, and an evaporation time of 30 minutes. The results obtained allowed us to make two conclusions: a) the relative losses of potassium and sodium in evaporation are determined by the acidity-basicity of the melt: in the acidic (granite) melt, the evaporation of the alkaline components is insignificant and noticeably less than in the basic (basalt) melt. In particular, the K_2O and Na_2O contents in the residual granite melt remained almost similar to their initial contents (the maximum decrease was 0.9 at 1300–1400 °C), while in the case of the residual basalt melt at the same temperature range, these contents decreased by about 3 times for Na_2O and 10 times for K_2O ; b) as a result of the evaporation of the basalt melt, a noticeable decrease of the K_2O concentration compared to Na_2O was observed, while in the granite melt, K_2O evaporates more slowly than Na_2O , that even results to certain increase of the K_2O / Na_2O ratio (Fig. 1).

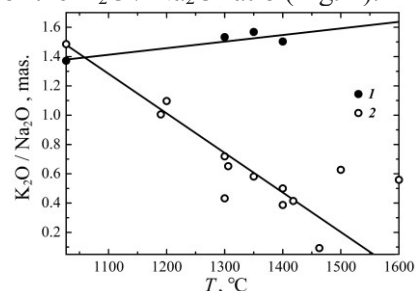


Fig. 1. Temperature dependences of the K_2O / Na_2O ratio in the residual melts of granite (1) and basalt (2) at evaporation in vacuum. The ordinate axis shows the initial ratio.

Our first conclusion completely coincides with the conclusions of the above-mentioned authors (Yu et al., 2003; Ebel et al., 2018), who proposed the dependence of alkali's evaporation on the total composition of the melt and the correlation of the process with the silica content. The dependence of the alkali evaporation vs. the melt acidity-basicity is essentially the same as the dependence on the silica content, since the silica content is the main "indicator" of the melt acidic property. Concerning to the second conclusion, unlike foreign authors, we observed inversion, that is, different and even opposite behavior of K₂O and Na₂O in environments of different acidity.

$$\frac{\partial \ln \gamma_{K_2O}}{\partial \ln a_{O^{2-}}} = \alpha_{K_2O} \text{ and } \frac{\partial \ln \gamma_{Na_2O}}{\partial \ln a_{O^{2-}}} = \alpha_{Na_2O}, \quad (1)$$

where γ_{K_2O} and γ_{Na_2O} are the K₂O and Na₂O activity coefficients, α_{K_2O} and α_{Na_2O} are the K₂O and Na₂O dissociation degrees in the melt.

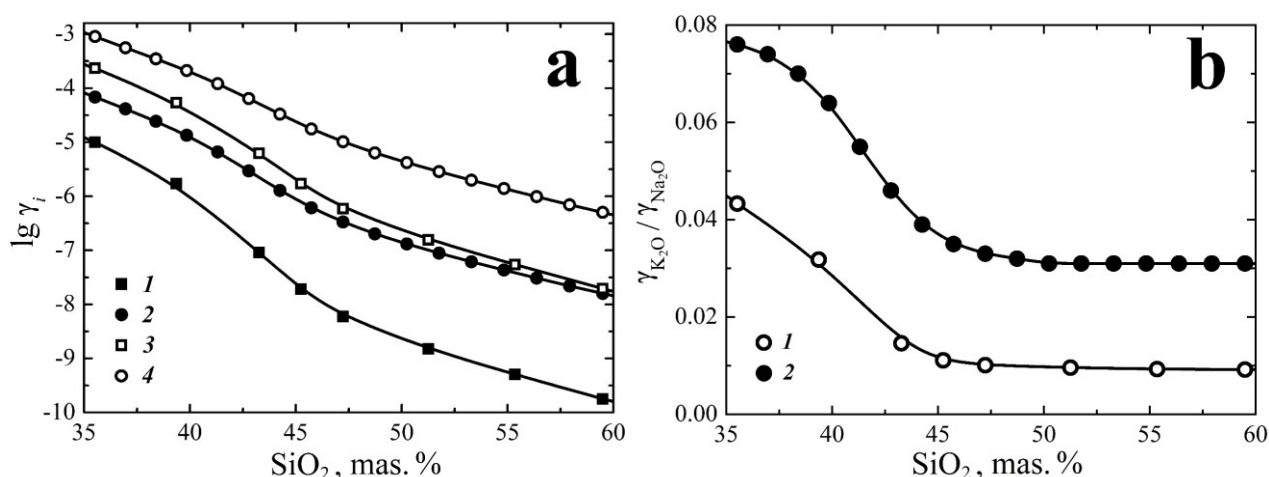


Fig. 2. The K₂O (1, 2) and Na₂O (3, 4) activity coefficients (a) and their ratio (b) in the K₂O–Na₂O–SiO₂ melts with a mass ratio of K₂O / Na₂O $\approx$ 3 / 4 at 1100 (1, 3) and 1400 °C (2, 4).

This equation indicates two trends: a) with increase of the melt basicity or, with increase the activity of oxygen ions, the alkalis activity coefficients will increase; b) due to the fact that $\alpha_{K_2O} > \alpha_{Na_2O}$, the K₂O activity coefficient will increase faster than the the Na₂O activity coefficient. Based on these dependences, it follows that in ultrabasic and basic melts, the activity coefficients of the alkaline components will be higher than in the medium and acid melts, and that with increase of the melt basicity, the ratio of the K₂O and Na₂O activity coefficients will increase. The opposite trend should be observed with a decreasing the oxygen ion

The experimental data in Fig. 1 are satisfactorily explained in the framework of the Korzhinsky's acidity-basicity interaction theory (Korzhinsky, 1959, 1963), which reveals the dependence of activity coefficients of melt components on the melt acidity.

As applied to the alkali evaporation, the acidity-basicity interaction theory predicts that the K₂O and Na₂O activity coefficients depend on the bulk index of the melt basicity, which is the activity of oxygen ions ($a_{O^{2-}}$). Oxygen ions are present in the melt due to the partial dissociation of the alkaline and basic oxide components. According to the Korzhinsky's theory, values of the K₂O and Na₂O activity coefficients are determined by the activity of oxygen ions:

activity, which should occur with an increasing the acidity of the melt or, what is the same, with an increasing the silica content in the melt.

To confirm the predictions of the acidity-basicity interaction theory, we calculated the K₂O and Na₂O activity coefficients in the K₂O–Na₂O–SiO₂ melts (Kracek, 1931) vs. the SiO₂ content (from 35 to 60 wt. % of SiO₂ and K₂O / Na₂O $\approx$ 3 / 4) at 1100–1500 °C. Thermodynamic calculations were performed in the framework of the associated solutions model (Shornikov, 2019). The standard Gibbs energy values for simple oxides, as well as for binary and ternary compounds in the condensed state were used as the initial data for calculating of the

oxide activity coefficients in the K_2O – Na_2O – SiO_2 melts. The results of the calculations are shown in Fig. 2. Fig. 2a shows a monotonous decreasing in the K_2O and Na_2O activity coefficients with an increasing the silica content in the melt, which corresponds to the predictions of the acidity-basicity interaction theory. It should be noted that the K_2O activity coefficients are almost an order of magnitude less than the Na_2O activity coefficients, which indicates greater "linkages" of potassium with silica compared to sodium in the melt. Fig. 2b shows the ratio of the K_2O and Na_2O activity coefficients as a function of the silica content in the melt. It should be noted that in the indicated range of SiO_2 contents, this ratio decreases almost in 3 times. Thus, the calculation results confirmed the trend predicted by the theory about the greater influence of the acidity factor on K_2O than on Na_2O .

A theoretical analysis of the relationship between the activity of the component and the evaporation rate was presented by Yakovlev et al. (1973). In summary, this relationship is the following: the evaporation rate of a material in a vacuum, taking into account the component activity, is described by the modified Hertz-Knudsen equation:

$$J = \varphi(\gamma p^\circ) / \sqrt{2\pi RTm} \quad (2)$$

where J is the evaporation rate or the flow of the material at evaporation from the melt surface; φ is the evaporation coefficient of the material; p is the saturated vapor pressure of the material; m is the molecular weight of the material; R is the gas constant; T is the absolute temperature. When a multicomponent melt is in equilibrium with its vapor, the partial pressure of the i -th vapor species (p) is determined by the activity (a) of this component in the melt. The relationship between the component partial pressure and their activity is expressed in the generalized Raoul-Henry law: $p = p^\circ a$, where p° is the equilibrium vapor pressure of the i -th substance taken in its pure form at a given temperature. By definition, component activity is calculated by multiplication of the component concentration (x) and its activity coefficient (γ), that is, $a = \gamma x$.

Equation (2) shows that the evaporation rate of a component from a multicomponent melt is determined not only by the pressure of this component taken in its pure form, but also by its concentration in the melt and the activity coefficient. With respect to the K_2O and Na_2O evaporation rates, the equation (2) can be written:

$$J_{K_2O} = \varphi_{K_2O} p_{K_2O}^\circ \gamma_{K_2O} / \sqrt{2\pi RTm_{K_2O}} \quad (3),$$

$$J_{Na_2O} = \varphi_{Na_2O} p_{Na_2O}^\circ \gamma_{Na_2O} / \sqrt{2\pi RTm_{Na_2O}} \quad (4).$$

From these equations it is easy to obtain an equation for the ratio of the evaporation rates of alkaline oxides at a certain temperature:

$$\frac{J_{K_2O}}{J_{Na_2O}} = \frac{\varphi_{K_2O} p_{K_2O}^\circ \gamma_{K_2O}}{\varphi_{Na_2O} p_{Na_2O}^\circ \gamma_{Na_2O}} \sqrt{\frac{m_{Na_2O}}{m_{K_2O}}} \quad (5),$$

which, neglecting the constants (m) and the variables depending solely on temperature (φ and p°), can be greatly simplified:

$$\frac{J_{K_2O}}{J_{Na_2O}} \approx \frac{x_{K_2O} \gamma_{K_2O}}{x_{Na_2O} \gamma_{Na_2O}} \quad (6).$$

The ratio (6) clearly shows that the K_2O and Na_2O activity coefficients are the most important parameters that determine the nature of fractionation at evaporation. As shown above, the K_2O and Na_2O activity coefficients are determined by the melt acidity-basicity properties. It follows that the $\gamma_{K_2O} / \gamma_{Na_2O}$ ratio will inevitably be reflected in the K_2O / Na_2O value in the residual evaporation products, which were observed in the experiment results presented in Fig. 1. Thus, we confirmed the correctness of the assumption of previous studies that the K_2O and Na_2O activity coefficients associated with the silica content in the melt are important factors controlling the evaporation process.

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