Abstract of the Project

"Research on Cosmic Matter on the Earth and in Space;

Research on the Biological and Geochemical Specifics of the Early Earth"

The present Project pertains to astrobiology. In recent years, astrobiological research has gained special relevance as there has been increasing evidence of the presence of life in the Universe. New limits have been found of the existence of living organisms (extremophiles) on Earth; fossilized microorganisms have been found in meteorites; organic molecules have been known to be highly incident in space.

As part of this project, it is proposed to continue the topic *"Biogeochemical Research on Cosmic Matter on the Earth and in Space; Research on the Biological and Geochemical Specifics of the Early Earth"* at JINR. Different scientific institutions already laid the solid groundwork for some parts (sections) of the topic, but it is the first time that the topic is presented in such an integrated way. It is conducted by the Astrobiology Sector of the Laboratory of Radiation Biology (JINR) with the participation of other JINR's subdivisions and collaborating scientific institutions. A number of studies is done jointly; some of them are performed at collaborators' facilities.

The following main fields of research are proposed within the topic:

- studies of microfossils and organic compounds in meteorites and in ancient terrestrial rocks;
- research on the synthesis of complex prebiotic compounds from formamide under exposure to radiation in the presence of meteorites as catalysts;
- biogeochemical studies of cosmic dust;
- studies of cosmic matter by nuclear physics methods.

1. Studies of microfossils and organic compounds in meteorites and in ancient terrestrial rocks

Microfossils are petrified microorganisms and products of their vital activity. They are important evidence of life occurrence in the Universe. Microfossils are present practically in all sedimentary and volcanogenic sedimentary rocks of the Earth's crust beginning with 3.9 billion years ago. Based on the experience acquired in bacterial paleontology, microfossils were confidently identified in carbonaceous chondrite meteorites, some of which can be older than the Earth. This can point to the fact that life in the Solar System emerged outside of the Earth and was probably brought to the Earth from space. Studying microfossils and organic compounds in meteorites and ancient terrestrial rocks will allow obtaining data on the forms of ancient terrestrial and extraterrestrial life and clearing up the problem of the origin of life.

2. *Research on the synthesis of complex prebiotic compounds from formamide under exposure to radiation in the presence of meteorites as catalysts*

One of the Astrobiology Sector's main fields of research is the problem of the origin of prebiotic compounds on Earth. As is known, meteorites have on their surface a significant amount of organic substances, many of which are necessary for the origination of life. It is assumed that they were synthesized during the gas phase and then were integrated into minerals. Studying the synthesis of these prebiotic compounds makes it possible to approach the answer to the question, "How could so complex structures develop on meteorites?" Once on Earth, these compounds might have originated life on Earth. The transition "from the inanimate to live" is still unclear, but the early stages of this process can be reproduced experimentally.

In particular, formamide (FA) ($HCONH_2$) — one of the simplest chemical compounds which is common both in the interstellar and interplanetary media — might have been such "initial material". The research performed at the Astrobiology Sector in cooperation with scientists of the University of Tuscia (Viterbo, Italy) has shown that more complex organic molecules can form from FA, including amino acids, carboxylic acids, sugars, nucleic bases, and even nucleosides. This diverse synthesis takes place when a mixture of FA and meteorite matter is exposed to ionizing radiation. After irradiation, a GC/MS method was used to identify the organic compounds in a complex mixture. Studying the action of different radiation types on FA mixed with meteorite matter can thus allow solving the fundamental problem of the formation of prebiotic compounds, which in turn underlie the formation of the first living systems. It is a pioneering research as modern studies of organic compound synthesis from FA mainly involve the temperature factor or UV radiation, which limits the research results to the synthesis of simpler compounds than have been obtained at the Astrobiology Sector.

3. *Biogeochemical studies of cosmic dust*

Cosmic dust (CD) research allows evaluating the regularities in the time distribution of cosmic dust falling on the Earth surface, which is important for the reconstruction of the geological history of the Earth and obtaining data on the paleoclimate. Research on CD structure, chemical and isotope composition, and biological properties helps solving fundamentals problems like the nature of interplanetary matter and its role in the origin of life. Therefore, of special interest is the detection of organic compounds in CD. Studying the physical and chemical properties of CD particles and comparing them with those of asteroids and comet nuclei determined by distance methods allows obtaining valuable information on the origin and evolution of not only these cosmic bodies but the Solar System as a whole.

CD studies are conducted according to the CD Research Program of the Scientific Council on Astrobiology of the Presidium of the Russian Academy of Sciences in cooperation with a number of scientific institutions.

4. Studies of cosmic matter by nuclear physics methods

The start of this topic at JINR allowed using nuclear physics methods to study cosmic matter. They include –

- determination of the elemental composition of cosmic dust and other extraterrestrial materials using multi-element neutron activation analysis at the IBR-2 reactor;
- evaluation of the proportion of heavy isotopes in cosmic matter samples using the IREN pulsed neutron source;
- identification of heavy isotopes with the IREN neutron spectrograph;
- determination of the structure of samples by X-ray and neutron tomography methods.

Results obtained in the past three years

1. Studies of microfossils and organic compounds in meteorites and in ancient terrestrial rocks

With a Tescan Vega 3 scanning electron microscope, more than 20 samples of meteorites (first of all, the Orgueil and Murchison carbonaceous chondrites) and terrestrial rocks have been studied at the LRB Astrobiology Sector. Several hundred images of fossil microorganisms have been obtained and analyzed, including cyanobacteria, actinomycetes, prasinophytes, testate amoebae, alveolates, etc. For the first time, pennate diatoms have been found in the Orgueil meteorite [1].

A micropaleontological research on early Precambrian rocks has been performed at Borisyak Paleontological Institute RAS. All bacterial paleontology studies have been done using a CamScan-4 scanning electron microscope (SEM) with a Link-860 microanalyzer, Zeiss EVO 50 SEM with an INCA Oxford 350 X-ray microanalyzer, and a Tescan Vega 2 ZMU SEM with an INCA Energy 450 system for energy dispersive X-ray microanalysis. Only fresh cleavages of rocks (ancient and modern) were used — sometimes, slightly etched by acids. It should be noted that the research deals with pseudomorphoses, not with fossilized microorganisms.

Research has been continued on the most ancient weathering rinds and Archean and early Proterozoic ferruginous quartzites of Karelia, Kola Peninsula, and Kursk Magnetic Anomaly

[2,3,4,5]; new data have been obtained on the biogenic origin of minerals; the role of life in the concentration of minerals on Earth has been evaluated; issues have been considered of the microorganism colonization of lava flows [6] and land [7,8].

In the collective monograph *Life and the Universe,* M.M. Astafieva has presented results of a micropaleontological study of low Proterozoic pillow lavas of Karelia and South Africa, where various pseudomorphoses of biogenic objects have been found. It has been concluded that the microorganism colonization of Earth could have started after Earth's crust had cooled down to 113ºC (other data indicate 120–130ºC); colonization processed along fractures and surfaces; and water provided protection from hard UV radiation.

In early Proterozoic ferruginous quartzites of the Kursk Magnetic Anomaly (the Lebedinsky mine; limonite-martite ores and striated ferruginous quartzites of the Korobkovsky ore deposit), fossilized cyanobacteria have been found, represented by trichomes merged into a single cover [2]. The minerals are deposited *in situ*. Morphologically, they are close to the modern representatives of the genus Microcoleus.

In early Precambrian Kejv proto-schists (the Kola Peninsula), nanobacteria deposited *in situ* were found. It is suggested that the presence of nanobacteria points to the involvement of the biological factor in the formation of host rocks; also, the presence of biofilms and nanobacteria suggests that the conditions of the external medium were unfavorable for bacterial life.

As part of the cooperation with Borisyak Paleontological Institute RAS, its Senior Scientist M.M. Astafieva *et al.* have conducted a series of bacterial paleontology studies of Precambrian rocks [9,10,11].

Acad. A.Yu. Rozanov [12] performed an analysis of the past two decades of astrobiological research. On the basis of this study —

- it has been suggested that remains of eukaryotic algae are present in the Low Archean rocks of the Isua formation;
- the oxygen-free character of the Archean and early Proterozoic atmosphere has been called into doubt;
- it has been concluded that water did not appear on Earth in significant amounts earlier than 4 billion years ago;
- the time of the probable emergence of the RNA world has been extended to 7 billion years ago.

Based on the example of archaeocyathan evolution, the importance has been shown of the ideas on evolution proposed by N.I. Vavilov, L.S. Berg, D.N. Sobolev, etc; and the creative role of natural selection has been questioned.

2. Research on the synthesis of complex prebiotic compounds from formamide under exposure to radiation in the presence of meteorites as catalysts

Research has been continued on the synthesis of prebiotic compounds from formamide with meteorites as catalysts under exposure to radiation. Materials have been published on irradiation with boron ions [13].

Experiments have been conducted on the synthesis of RNA and DNA component nucleosides in a formamide (FA) — meteorite matter system exposed to ionizing radiation (accelerated protons). Matter of chondrite meteorite NWA 1465 was used as a synthesis catalyst. The pathway has been determined of the general reaction leading to the synthesis of ribo- and 2'-deoxyribonucleasides from sugars and purine nucleotides under exposure to 170 MeV protons in the presence of NWA 1465 matter. The yield of the reaction products is much higher in the presence of formamide and meteorite matter than in the control. The results have been published in *Scientific Reports,* a Nature Research journal [14].

A number of experiments on abiotic phosphorylation of nucleosides have been conducted. This subject is a serious obstacle to research on the formation of the first living organisms. An optimal pathway has been deduced of the synthesis of adenosine nucleotides from adenosine ($C_{10}H_{13}N_5O_4$) and sodium dihydrogen phosphate (NaH_2PO_4) under exposure to 170 MeV protons in the presence of the matter of the NWA 2828 carbonaceous chondrite meteorite as a catalyst. As a result, besides the target nucleoside, found in the mixture were its derivatives, adenosine polyphosphates and inorganic polyphosphates, which underscores the system's high reactivity. These experiments reproduce, to some extent, the conditions in space or on the early Earth, when solar wind protons not only passed through interplanetary space but also reached Earth's surface. The experiments have thus allowed modeling a prebiotic phosphorylation scenario.

In all four reaction mixtures, formation has been observed of alicyclic and cyclic adenosine nucleotides. It has been established in the experiments that the total yield of adenosine nucleotides significantly increases when the reaction mixture contains formamide (NH_2CHO) and meteorite matter. The results of this research have been submitted to *Chemistry — a European Journal*, 2019.

3. Biogeochemical studies of cosmic dust

M.V. Frontasyeva *et al.* [15,16] studied in 2018 cosmic dust from moss samples collected in Belarus, Georgia, Russia, and the U.S. Microanalysis showed that the samples contained clastic, anthropogenic, and cosmic dust particles. The latter consisted most often of Fe, Fe-Ni, and Fe-Cr minerals.

Compared with Arctic ice, Antarctic ice contains much less terrestrial and no anthropogenic dust. S.A. Bulat *et al.* [17,18] performed in 2018 a cycle of studies to search for cosmic dust particles in Antarctic ice. Found were iron-stone micrometeorites, but no carbonaceous chondrites.

4. Studies of cosmic matter by nuclear physics methods

M.V. Frontasyeva *et al.* (Laboratory of Neutron Physics, JINR) have performed at the IBR-2 reactor neutron activation analysis of cosmic dust particles. Samples were collected in Belarus, Georgia, Russia, and the U.S.

Most of the particles, when passing through the atmosphere, are subject to melting. It is especially typical of larger particles. Cosmic spherules have been observed; these particles are relatively easy to identify. They are the background magnetic component of cosmic dust. In the latter, Fe, Fe-Ni, and Fe-Cr minerals have been found most often.

Organizational activities

- A chemical laboratory has been created.
- An atlas of Orgueil meteorite microfossils has been prepared.
- The makeup of Dubna University's astrobiology textbook has been done.

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Cost evaluation

To improve the laboratory basis of the Astrobiology Sector of the LRB JINR and collect and analyze cosmic and terrestrial matter samples, about 130,000 USD will be required during three years. The costs include the construction and equipment of the block of clean and cold rooms and the price of the laboratory instruments and expendable materials. The table below shows the cost breakdown by year (see the Schedule) in thousand USD.

	1st year	2nd year	3rd year
Year	2020	2021	2022
Equipment	40	30	30
Expendable materials	5	5	5
Payments for agreement-based scientific research work	—	—	—
Travel allowance	5	5	5
Total	**50**	**40**	**40**

Work schedule

2020

Expansion of the meteorite and terrestrial rock collection. Resupplying with equipment the chemical laboratory for studying the synthesis of complex prebiotic compounds from formamide. Analysis of prebiotic compounds and catalysts. Work on the creation of an illustrated atlas of microfossils in the Murchison meteorite. Preparation of an experiment on studying the possibility of the synthesis of prebiotic compounds from a formamide — meteorite matter mixture in open space aboard the Bion-M spacecraft. Evaluation of the research results.

2021

Further cosmic dust collection; sample preparation and analysis. Identification and studies of microfossils and organic matter in meteorites and the most ancient terrestrial rocks. Analysis of prebiotic compounds and clearing up the catalysts' nature. Publication of an illustrated atlas of microfossils in the Murchison meteorite.

2022

Research on extremophiles, the underground biosphere, weathering rinds, the cryolitic zone, meteorite matter, and cosmic dust.

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