SCIENTIFIC JOURNAL
EARTH'S CRYOSPHERE

Earth`s Cryosphere, 2014, vol. XVIII, No. 4, pp. 3–10 http://earthcryosphere.ru/

BASIC PROBLEMS OF GEOCRYOLOGY

THE CRYOSPHERE: A HOLISTIC APPROACH

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The research of the mosaic, contrasting, and changeable cryosphere requires a holistic approach and efforts of different scientists through interdisciplinary projects. To realize this approach, it is crucial to update the theoretical and methodological background. Cryology can provide knowledge relevant to many issues of life and Earth sciences. Specifically, the cryosphere is an important element in models of origin and evolution of planets and terrestrial life.

Holistic approach, interdisciplinary research, cryology, cryosphere, ice, cryotraceology, biosphere evolution, gas hydrates, metastable state, drop clusters, hydrogen bonds

Nowadays, when knowledge is growing rapidly and various sciences are interfingering while the education principles are changing, it is important to outline the features of cryology as a science of the future, broaden its scope, and provide guidelines for the objectives and expected results.

The idea of future permafrost research hardly can be exact, given the fast progress and convergence of different sciences. The increasing amount of knowledge was difficult to handle already in the time of Aristotle who said "the known is known to but a few". Currently the very tools of learning are advancing at a great pace: information technologies, databases, and computerized search, analysis, and synthesis of data, though the man remains privileged to formulate the problems and to interpret the solutions.

Thus, we can only outline the future prospects proceeding from the knowledge of cryosphere components. This may be rather a Picasso-style image, open to updates and changes of elements not disturbing the whole artwork, but it should become a guide to the subject, structure, and content of the science, and possible professional diversity within it.

Looking back to the 20th century, I realize that the decades of permafrost studies have been one and the same "dance", exactly following the idea of the "choreographer", though the "steps" changed direction and length. Even moving from one permafrost area to another, from Willy's site to Billy's site, we have been stuck, as if remaining within the "prokaryotic paradigm". A breakthrough in cryology is needed to join the "eukaryotic world", which has triumphed and chosen a different way of reproduction after a bifurcation point. The prokaryotes have survived without changing much in the conditions the eukaryotes failed to conquer; they yielded to the natural diversity, but may be waiting for new bifurcations to revenge.

The creation of a "new dance" and the turn to the "eukariotic path" in cryology began after the "bifurcation" of interdisciplinary research providing integrated data on all planets and their satellites. The large complex system of cryosphere obviously should be studied top down, from the general to the special. Otherwise, new knowledge will remain within the limits of elementary events presumed to belong to some general system which never can be modeled correctly [*Zavarzin, 2004*].

In this paper I touch upon two global problems of the world science, those of Earth's history and life origin, where cryology, viewed holistically, can make a valuable contribution.

Vladimir Vernadsky, prominent Russian mineralogist, geochemist, and great thinker of the 19–20th centuries, wrote: "Ice and snow accumulating in the biosphere influence strongly its structure and change the living matter due to their effect on life and hydrography" [*Vernadsky, 2004*]. This idea is valid for the recent geological past, as well as for the time of earliest life, for both pre-Darwinian and Darwinian evolution. Meanwhile, the role of ice and snow in the Earth and biosphere history appears to be still underestimated, for example, in two big recent books on the subject [*Galimov, 2008; Gordienko, 2008*]. The evidence on the interaction of cryosphere with other Earth's spheres, as well as new data obtained by permafrost biologists and geochemists, failed to enter the "big science". Possibly, because they worked apart from other scientists in the pre-interdisciplinary time or were not active enough to sweep the scientific community with their wonderful discoveries, though the recently gained knowledge of permafrost is becoming part of basic ideas in biology and geology.

The understanding of the causes of glacial events and their role in the evolution of biosphere has not progressed much since Melchior Neumayr, a brilliant German and Austrian paleontologist and geologist of the 19th century, wrote his *Erdgeschichte* [*Neumayr, 1887–1895*]. He ended the chapter on ice ages saying that cooling during the glacial epochs apparently covered the whole globe, but the causes and duration of those events were unclear. Further he wrote that all attempts to explain the ice ages failed because the facts were poorly investigated, and concluded that studying the past climates was especially important and collecting the respective facts would be the only research objective for a long time [*Neumayr, 1887–1895*]. Although facts are important as they can make basis for probabilistic models even if remain unexplained, but we have to admit that the permafrost science is still collecting facts rather than being trying to explain them.

Some breakthrough in understanding the climate forcing is due to the works by *Milanković* [*1930*], but this is not enough.

Another thinker who suggested explanations for the Earth's history, Alfred Wegener, a German polar researcher, geophysicist and meteorologist, was born 135 years ago. He advanced the theory of continental drift (*Kontinentalverschiebung*) in 1912 hypothesizing that the continents were slowly drifting around the Earth [*Wegener, 1929*]. The idea, which was not widely accepted before the 1950s but eventually gave rise to today's plate tectonics, was inspired by his observations of ice sheet dynamics during the Greenland expedition. To commemorate this discovery, permafrost scientists may contribute to the Earth history studies with data on the role of glaciations in the evolution of abiogenic and biogenic components of the crust.

The current permafrost research is mainly confined within the Quaternary and often overlooks the most interesting things that occurred 2 or 2.5 byr earlier. Since that time cold spells of different lengths and strengths became regular, while the beginning and end points of the glacial cycles correlated with changes in atmospheric composition (CO_2 and sulfur). This correlation has been quite well studied, but the previous history likewise requires advanced approaches and hypotheses, in the view of the existing controversy about the “hot” or “cold” earliest Earth.

The cryosphere is super-systematic, as follows from the fact that ice had existed prior to the origin of the Solar System with its planets, and even before water and life appeared on the Earth. Moreover, it will remain in the Universe after the Sun expands and heats up and after our Earth becomes a lifeless hot planet. It will apparently arrive at this sad end in a few billions of years, which is quite a short span in the history of the Universe.

Evolution biologists state that “nothing in biology makes sense except in the light of evolution” [*Dobzhansky, 1973*]. We may add that the evolution of life and its environment inevitably experiences effects of changes in the Earth's cryosphere. Therefore, investigation into cryotic and cryogenetic systems in the context of the global geological and biopsheric history will certainly become a key element of the future cryology.

In the super-systematic hierarchy of the cryosphere, the Earth's permafrost is a second-order component, with its own subsystems (atmospheric cold layers, land cover, subsoil permafrost, etc.). The greatest known depth of cryotic processes corresponds to the occurrence of continental and oceanic gas hydrates making a belt of warm permafrost. The presence of this zone with phase transitions of deep fluids implies that cryology should operate with concepts of supercooled water and ice (ice-lake material) at great depths, not to miss the essential element of the geosphere produced by high-pressure cryogenesis.

Before going forth into the outlined problems, it is pertinent to specify the model of the Earth's cryosphere (Fig. 1), with its parameters highly variable in different directions. Above the earth's surface there is

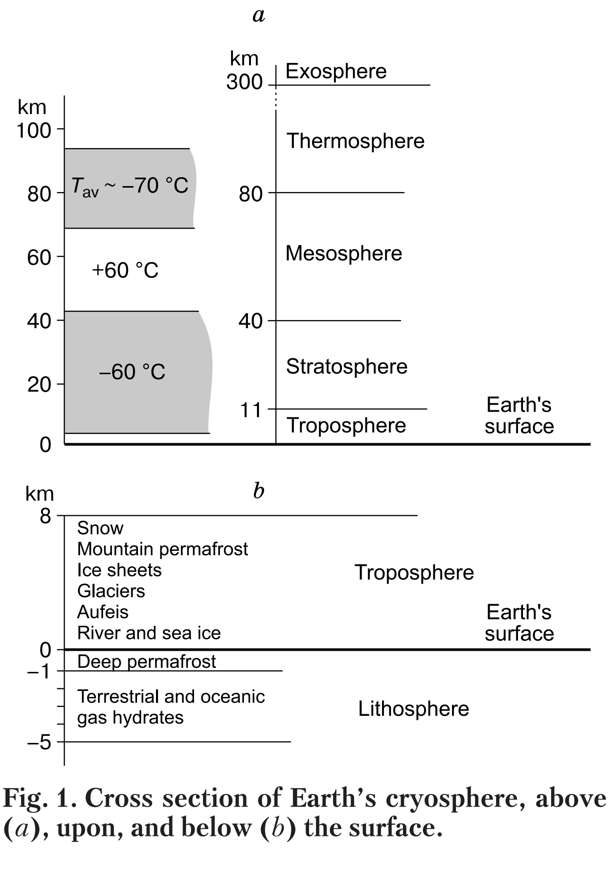

Fig. 1. Cross section of Earth's cryosphere, above (*a*), upon, and below (*b*) the surface.

the troposphere, 8–10 km, 10–12 km, and 16–18 km thick in the high, middle, and tropic latitudes, respectively, which stores up to 80 % of air and 90 % of vapor. The average near-surface air temperature is about +26 °C at the equator and –23 °C at the North Pole, the respective values at the top of the troposphere being about –70 °C and –65 °C (winter) to –45 °C (summer).

The air absorbs the outgoing Earth's radiation, which is mainly at infrared wavelengths, and cools down upward with the average gradient 0.65 °C/100 m. The light and warm near-surface air rises and cools down upon expansion when it reaches the zone of low pressure. This cooling effect was noted by *Mendeleev* [*1950*] and described in his works on meteorology.

Thus, the troposphere has a layered structure, with roughly the same mass of air in the warm and cold layers. The static stability of the atmosphere increases at its boundary with the stratosphere, especially in the tropic latitudes, within a transition zone (tropopause) varying in height and in thickness, from a few hundreds of meters to 1–2 km, because of turbulence and convection under the control of air circulation and seasonal variations.

The upper part of the lower cold layer is located in the nearly isothermal stratosphere, but the air warms up rapidly above 20 km reaching 0 °C at 40 km and a few tens of degrees above zero at ~50 km above the surface. The warm layer owes its origin to ozone which absorbs the sunlight. The formation of atmospheric ozone about 400 myr ago let the life step off the ocean to the land. Without the ozone layer, the tropospheric cooling would continue as high as 80 km, i.e., the two cold layers appeared quite recently in terms of geological time.

The atmosphere above 90 km warms up due to short-wavelength (130–170 nm) radiation which ionizes molecular oxygen but does not penetrate below this height. Negative temperatures in the upper cold layer result from low contents of ozone. Stable molecules show a barometric distribution within ~100 km in the atmosphere, decreasing in number exponentially with height. A similar distribution is observed in atmospheric ozone.

The Martian atmosphere contains little oxygen, which causes the lack of an ozone layer (though ozone itself exists, making 3 % together with C, O, and H_2O) and the low temperature of a single cold layer with a minimum of –150...–160 °C at the height about 120 km (from *Viking* data).

The cryosphere has become a subject of active research (including by many recently formed institutions which have not yet joined the International Permafrost Association, IPA), and new information is hard to follow and analyze. It is urgent to update the terminology and broaden the meaning of basic concepts tested by time, in order to reach better understanding among permafrost scientists.

Broadening is necessary first of all for the concept of ice, the key element of the terrestrial and extraterrestrial cryosphere, which is often limited and superficial [*Ivanov, 1998*]. The main limitation comes from its ties to water and to the water-ice transitions. Ice is often interpreted as a mere by-product of water transformations: What people commonly speak of are three phase states of water but not of ice. Note that H_2O is the only matter for which all its states have their names in many languages, because of its great significance in the human life.

The definition of planetary ice can be as follows: ice is a chemical compound of main elements in the lower atmosphere of planets; it is a solid which can transform into liquid or gas under temperature and pressure changes; it commonly has a crystalline structure and encloses macro- or micro-inclusions of fluids, gases, and solids.

This definition of planetary ice (which can be adapted to cosmic ice by using the more general concept of "a medium" instead of the "lower atmosphere of planets") allows treating it in a broad spectrum of compositions, structures, states, and functions rather than as a purely terrestrial phenomenon.

The numerous links of the versatile phenomenon of ice are presented in Table 1, which once again proves valid the law of ecology by Barry Commoner

Table 1. **Ice as a multifunction system**

1. Physicochemical system	2. Physical system	3. Natural material	4. Information system	5. Control system
1.1. Crystal-chemical system 1.2. Geochemical system 1.3. Ecological niche 1.4. Multifunction barrier 1.5. Climate system component 1.6. Biosphere component	2.1. Material body 2.2. Crystallographic system 2.3. Geosystem component 2.4. Mechanic system 2.5. Multi-function barrier	3.1. Mineral 3.2. Rock 3.3. Ice massif 3.4. Ice geosystems 3.5. Geological object 3.6. Geographic object 3.7. Planetary object 3.8. Superplanetary object	4.1. Source and receiver of weak energy fields 4.2. Recorder of events 4.3. Natural archive (information resource)	5.1. Control of environment parameters 5.2. Matter and energy converter 5.3. Concentrator of excess substances 5.4. Resource of chemical elements 5.5. Accumulator of emergent systems 5.6. Standard of environment conditions

saying that “everything is connected to everything else”. Being based on the known components, the table will allow integrating the concept of ice into the Earth and biosphere history research.

The table is a synthesis of explicit or implicit evidence and ideas of many scientists, my “silent” coauthors, which I appreciate but fail to cite them all. In this I follow the example of Robert Fleagle and Joost Businger who acknowledged the “silent council of many authors” in the preface to their *Introduction to Atmospheric Physics*, where they also referred to “the wisdom of the perceptive observer” who wrote: “Von einem gelehrten Buche abgeschrieben ist ein Plagiat; von zwei gelehrten Büchern abgeschrieben ist ein Essay; von drei gelehrten Büchern abgeschrieben ist eine Dissertation; von vier gelehrten Büchern abgeschrieben ist ein fünftes gelehrtes Buch” [*Fleagle and Businger, 1963*] (copying from one scientific book makes a plagiary; copying from two scientific books makes an essay; copying from three scientific books makes a dissertation, and copying from four scientific books makes the fifth scientific book).

Till recently the views of ice were wrong in many aspects [*Maeno, 1988*], including the ideas of its physical properties studied even by Nobel Prize winners in the 1940s, 1950s, and 1970s (e.g., by Linus Pauling awarded the Nobel Prize in chemistry in 1954 [*Pauling, 1935*]).

There are different properties brought together in ice, which is at the same time elastic and plastic, crystalline and amorphous, semiconducting and dielectric, light and hard (lighter than water but harder than steel). Ice has no zero entropy at the absolute zero temperature; it follows a certain trend towards an ideal structure: its order increases while entropy decreases with time at a constant low temperature [*Maeno, 1988*].

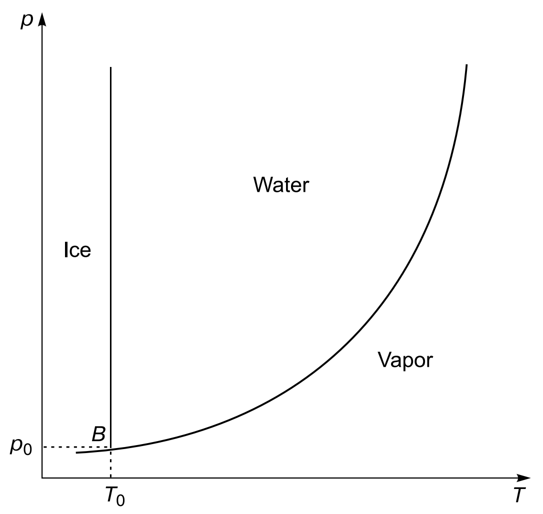

Fig. 2. Triple point (*B*) at T_0 = 0.0075 °C and p_0 = 6.1 GPa.

Snow is white because it does not absorb light, while ice is transparent because it lacks free electrons. Snow consisting of ice crystals is white for the same reason as powdered transparent glass. Ice most often has a quasi-liquid surface, with water molecules chaotically distributed in the quasi-liquid layer but with ordered dipole orientation at subzero temperatures. Ice crystals are built uniquely of hydrogen bonds, i.e., ice provides a standard for estimating hydrogen bonds. On the other hand, hydrogen bonds are indispensable in proteins, nucleic acids, or biopolymers. They were crucial to the life origin as all biochemical processes in living beings are associated with breaking and forming hydrogen bonds.

Water molecules in ice crystals are positioned in the way that electrostatic and dispersion forces (deformation of electron clouds in two convergent molecules when attraction forces arise) are balanced with the repulsion forces of quantum-mechanic origin. This condition defines the 2.76 Å distance between H_2O molecules (“length” of hydrogen bonds) [*Maeno, 1988*].

Hydrogen bonds break when ice melts and become all broken in vapor. Thus, the system ‘water-ice-vapor’ has either strong covalent (water), or purely hydrogen (ice), or broken hydrogen (vapor) bonds. The life conditions correspond to the triple point in the phase diagram of H_2O (Fig. 2). Therefore, the weakness of hydrogen bonds may be responsible for the possibility for organisms to exist freely outside water, i.e., in the atmosphere (troposphere) and on the land.

Hydrogen has been critical to the energy budget of oldest biological systems [*Fedonkin, 2008*] being the primary source of electrons and protons, the basic substrate of microbial life, and the energy base of metabolism [*Wackett et al., 1994*]. It controls the strength and plasticity of macromolecules; molecular hydrogen (H_2) maintains trophic (energy) relations between microorganisms that live on different substrates; this is actually the primary builder of an ecosystem prototype. In the world of prokaryotes, hydrogen, as an energy-related element, guided competition among many groups. Furthermore, the reducing ability of molecular hydrogen and its capability of forming proton gradients as a way to save energy, as well as many other properties, evidence that hydrogen has been the most important element and a key agent in the life origin.

The cryospheric approach can be useful also in chemical and mathematical models of the earliest Earth which will succeed the present hypotheses of planet formation and life origin with advances in computing, chemistry, and physics.

Turning back to the plate tectonics, it is crucial to constrain the reliability of data recovered from the crust, with due regard to the history of proto- and super-continents in the context of atmosphere-geosphere interaction. The moving plates obviously interacted with the atmosphere above them, which differed from its present counterpart in both structure and composition. Knowing that H_2O, CO_2, NH_3, and CH_4 kinds of ice exist in different planets and their satellites, it is reasonable to presume that some of them existed on the Earth in the geological past.

An atmosphere with a pressure of 6–7 mbar, as well as water basins existed already at 4.4 to 4.1 Ga, judging by the ages of the oldest Australian zircons. Tracks of ^{129}Xe (^{129}J fission product) show its dynamics on absorption by gas hydrates [*Adushkin and Spivak, 2000*]. Therefore, hydrates (a component of the cryosphere) may have existed billions years ago. The +200 to –100 °C temperature cycles of the early Earth imply different phase transitions [*Varfolomeev et al., 2008*], i.e., the history of the planet included cryotic events. The hypothesis of a "snowball" Earth appears quite plausible at the dawn of the geological evolution as intense outgassing and the ensuing cooling of the atmosphere were favorable for ice accumulation.

The cyclic processes in the cooling mantle changed both the atmosphere and the growing crust, and their effects were apparently quicker and more prominent than now, since the thin atmosphere and crust were too weak barriers.

The "snowball" scenario, when the planet was fully covered with ice, may have repeated many times, and the task of cryology is to discover traces of those periods. Traces of cryogenesis were discovered, for instance, in Carboniferous rocks [*Slagoda, 2005*], and traces of numerous glaciations were found at other stratigraphic levels as well. Much evidence of past glaciations has gone with material recycled in the mantle but some has survived from 4 Ga, including in the territory of Russia and Former Soviet Union.

It is clear why permafrost scientists and glaciologists focus on the Quaternary with its four cold events that left numerous imprints, but this is an easy way of research. The interest to recent glaciations takes mind off the earlier cryosphere history, whose traces are rapidly disappearing with time. In this respect I suggest to create a special new field of *cryotraceology* to concern with interaction of ice with biotic and abiotic components of the medium. Nothing passes without leaving a trace; the problem is to find it. The modern facilities allow detecting various imprints of events, but a systematic approach and advanced search are required.

Every effect receives a response, explicit or implicit, as noted metaphorically in the quote of Kozma Prutkov saying "Snap a mare on the nose and she will flap her tail". Thus, effects can be traced back from responses. This is, for example, the effect of the environment on self-organization of systems in nature. The pentagram and pentagon shapes of many plants and animals from starfish to humans may record some remote effect, or possibly reflect something like solar prominences? The hexagonal symmetry in crystals and snowflakes might be a trace left by our far or close neighbors in the Universe. On the other hand, the hexagonal geometry is known to provide the most efficient energy dissipation and energy gain [*Kadomtsev and Rydnik, 1981*]. The hexagonal geometry is widespread in nature: clouds making almost ideal hexagons with sides of several kilometers long, or hexagonal granules on the Sun surface looking like Bénard convection cells [*Pechurkin, 1988*], etc.

The evolution of the Sun and the responses of planets and their satellites to radiation changes with time have received little attention so far. With the advances in studies of the Sun and the Universe, it is possible to proceed from mere theory to real physics. For example, the inferred heating of the Sun for the first ~500 myr of its history and the related increasing radiation received by planets at different distances from it gives us two parameters for a model: increasing radiation and distance-depending responses of the planets. Additionally, the model should take into account the properties of the planets which differ in their orbital cycles (from 87 days for Mercury to ~165 years for Neptune), interior heat, surface structure, atmosphere composition, thermodynamics, etc.

It is time to extend the models of Earth's climate to the cryosphere models of the Solar system with planets as its subsystems. The climate models will become more realistic if they account for the dynamics of layered cryospheres in different celestial bodies. Investigation into other planets may provide clues to the Earth history which, in its turn, will improve the interpretation of records from space missions.

Permafrost scientists should become more involved into solving the basic problems of science. Among the four major issues of matter structure, life origin, mind origin, and space-time problems, we can contribute to the second one with new facts and plausible hypotheses.

The Universe evolution, since the very first origin of the matter from protons, neutrons, and electrons released by the big bang, has been closely associated with hydrogen which, together with helium, formed during cooling. Then there followed aggregation of elements into the future galaxies, clustering of the matter into H and He stars, thermonuclear fusion, new bangs, synthesis of elements (O, N, C, etc.), birth of new stars, and origin of elements included into the periodic table or not yet synthesized on the Earth.

Cryology deals mostly with hydrogen and oxygen: for billions of years ice, based on hydrogen bonds, has been an agent in natural processes, including the origin of life. Perhaps, ice, water, and vapor are the systems that concentrate hydrogen and thus may be responsible for the lack of H on the Earth relative to the extraterrestrial space and the Sun.

The terrestrial life obviously began on the Earth. The idea of its extraterrestrial source, like the divine origin, explains nothing but poses the question of how life could originate in the place where it came from. Furthermore, this idea contradicts the universally accepted crucial role of environment. The models of terrestrial life origin imply that the environment had been preparing to that moment for hundreds of millions of years after the formation of the Solar system, while the extraterrestrial life would have left some other environment, travelled through the killing UV radiation, survived the catastrophic collision with the Earth and then adapted to its hot crust, and after all have preserved its liquid. Long-term adaptation to the environment is indispensable even for extremophilic organisms to survive and reproduce. By stating that any living object would be "always distinctly separated from its environment", *Parmon* [*2004*] seems to have meant something different. Otherwise, the question is whether this object can survive apart from the environment, and the answer is clearly "no".

More plausible is the idea of physicochemical concentration of abiotic organic matter in probiotic forms at a certain point of chemical evolution. The pre-biological selection acted upon whole phase-separated structures rather than on isolated molecules [*Pechurkin, 1988*]. Or rather it was coevolution in the conditions of stable non-equilibrium [*Moiseev, 1997*]: living matter was synthesized from abiotic matter in special environment conditions, which maintained the life and its evolution while changing continuously together with it.

Many studies in this line follow the ideas of *Haldane* [*1929*] and *Oparin* [*1968*] on the chemical origin and evolution of life, and formation of complex proteins out of simpler compounds. Another similar hypothesis suggests hydrocarbon crystallization of life [*Yushkin, 2004*] meaning that minerals may have catalyzed the origin of more complex hydrocarbons and transferred a part of their structure (in terms of information) to the first biological molecules. The model of *Yushkin* [*2004*] shows that many biological processes were guided by crystallization and ordering common to the whole nature and that the formation of biological structures was a transition to a higher ordering level.

Not going far into details of these hypotheses, it is pertinent to mention recent related discoveries. This is, for example, the discovery of drop clusters [*Fedorets, 2004*] consistent with the idea that molecular aggregates further clustered in drops and thus made basis for proto-biological systems [*Oparin, 1968*]. The drop clusters, stable dissipative structures in the form of ordered tiny condensate balls that appear in the gradient zone over a locally heated liquid phase, may be a missing link between the organic and inorganic matter. This phenomenon proves again that water and ice are an inexhaustible source of wonders.

The latest discoveries in mathematics, physics, and chemistry often become part of other sciences as ready-made solutions and guidelines. With respect to the drop clusters, there are two points to mention: the lack of attention to this phenomenon and its easy accessibility to studies. Although indispensable in the everyday life of people, the existence of drop clusters long remained unknown (and still is little known, years after the publication [*Fedorets, 2004*]). The model requires an update as to the very mechanism of phase change related to the origin of an intermediate structure.

Drop clusters may also form out of liquids other than water. Therefore, such structures may have existed on the early hot Earth prior to the origin of water. Drop clusters result from vapor condensation, i.e., molecular transition to a structure with stronger bonds, while the bonds between drops remain weak. These clusters mainly have hydrogen bonds, the same as in DNA between its spirals, in RNA, and in proteins. Drops immersed in the liquid carry the formed bonds in their interior, and no abrupt change in conditions occurs. Perhaps, these mysterious drops provide an example of a mechanism of ordered evolution in the Universe sought by the scientists? Once, being under the impression of the drop clusters discovery, I was watching berries from the fridge (−18 °C) to thaw on a stove, and thought that the drop clusters must arise in the same kind of vapor as that above the bowl with berries (but at +60 °C). The cold berries, with the fire below and the vapor above, make a miniature model of the troposphere and the stratosphere, a layered model of drop cluster formation in a broad temperature range: a cold layer sandwiched between two warm layers.

Drop clusters are better candidates for concentrators of substances from the "primordial soup", including the components required for the formation of RNA and DNA. In this respect they are "soft minerals" comparable with the mineral catalysts of complex hydrocarbons in the hypothesis of *Yushkin* [*2004*].

The time factor likewise supports the idea of drop clusters as a matrix of proto-biological structures: hydrogen and oxygen are coeval with the primordial matter and have been agents of all processes in the Universe. Therefore, they are "genetically" much older than montmorillonite or other minerals invoked in the cited models.

Note again the perfectly round shape of drops and their stable off-equilibrium state as a basis of coevolution with the environment. The drop surface is the prototype of the first biological membranes. Given that any organism contains 85–90 % of water, it is clear that the proto-biological evolution is contemporary to the Universe, as well as the ice, a "veteran" of the world.

The Russian scientists have been aware of the necessity for bringing together cryology and biology since the earliest permafrost studies in the USSR. The exciting finds of mammoths or reviving insects recovered from frozen ground aroused great international interest already in the first half of the 20th century. Although the existence of permafrost remained long neglected ("no forest would grow on permafrost"), it occupied its proper place in the European science, largely due to the works of *Humboldt* [*1805, 2009*].

The today's works in cryobiology are as fascinating to read as science fiction, with all those caterpillars and butterflies that return to life after staying long frozen to −269 °C, or invertebrates (rotifers and nematodes) that withstood freezing to −271 °C in the dry state. After all that, the life in natural permafrost would appear a "resort" for microorganisms. Judging by evidence from the *Vostok* ice cores [*Tsyganova and Salamatin, 2006; Kotlyakov, 2012*], nature has been much more prudent than man in maintaining the temperature regime for hundreds of thousand years having provided smooth cooling and warming, exactly what is needed to let organisms adapt to new conditions. The knowledge gained from paleobiota is just a good beginning, while the main discoveries are to come.

One practical objective of cryology is to get the same life support from permafrost as the extremophilic microbes do. In this respect ice can be considered a habitat or, more precisely, a stable non-equilibrium coevolving system in which microorganisms are intrinsic components of ice or frozen rocks. Getting beneficiary effects from products based on ice which contains (or contained) paleobiota is a realistic objective of the nearest future. In the same way as making cosmetics using normal saline which stored a stem cell [*Brushkov et al., 2010*], it is possible to make medicinal substances from ice formerly inhabited by bacteria.

Another challenge for joint efforts of biology and cryology is understanding the function of ice in the punctuated equilibrium of Eldredge and Gould in the context of sustaining life. Ice has too many advantages over other media being a shield against killing radiation, a thermostat with the minimum temperature gradients, protection against chemical or biological mutagenic agents, and, finally, a constantly renewing medium.

There are many aspects to study in ice: be it micro-volume friction inside ice which is enough for film water to arise, or hydrogen bonds used also by proteins, RNA, and DNA (see above). Anyway, we are facing new challenges in studying cryotic and cryogenetic systems in order to answer the eternal questions Who? What? Where? When? How? and How much?

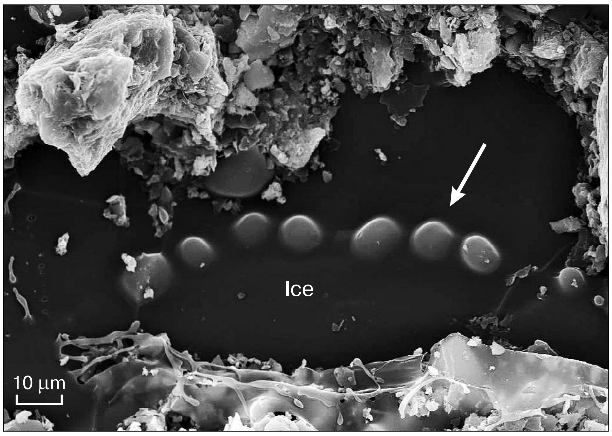

Fig. 3. Cells in an ice vein (shown by arrow), Mamontova Gora (Mammoth Hill) site. Photograph shot on 03.02.2010.

For instance, recent scanning electron photomicrographs obtained by V. Rogov [*Melnikov et al., 2011*] showing microbial organisms in ice veins (Fig. 3) within frozen ground arouse many questions: why the cells (bacteria) are in the middle of the ice vein? Are they moving or fixed? If they move, which are the mechanisms and speed of the motion?, etc.

The cryosphere is interesting in many aspects: in terms of physics, chemistry, biology, geology, and geography. In the latter respect it is a prominent result of continuous effect of the solar energy and deep processes on the Earth's surface. It is exciting to study, for example, production and destruction processes, such as river freezing, which are of the same scale as turnover in water and bottom sediments [*Kondratieva, 2010*].

Thus, the studies of the mosaic, contrasting, and changeable cryosphere, which appeared together with our planet at least in some of its elements, require a holistic approach and joint interdisciplinary efforts.

The study was supported by grant 14-17-000131 from the Russian Science Foundation.

References

Adushkin, V.V., Spivak, A.A., 2000. Release of radioactive products of underground nuclear explosions into the atmosphere, in: Radioactivity in Nuclear Explosions and Emergency, Gidrometeoizdat, St. Petersburg, pp. 139–140. (in Russian)

Brushkov, A.V., Griva, G.I., Karnaukhov, N.N., Melnikov, V.P., Repin, V.E., Sukhovei, Yu.G., Milovanov, V.I., Filin, V.A., 2010. A strain of *Bacillus* sp. bacteria, with immunomodulatory and geronto-protective activity. Patent 2413760 RF. Claim 2009116228/10. Claimed on 29.04.09, published on 10.11.10, Bull. 24.

Dobzhansky, Th., 1973. Nothing in biology makes sense except in the light of evolution. Amer. Biol. Teacher. 35 (3), 125–129.

Fedonkin, M.A., 2008. The role of hydrogen and metals in the evolution of metabolic systems, in: Problems of Biosphere Origin and Evolution, Librokom, Moscow, pp. 417–437. (in Russian)

Fedorets, A.A., 2004. Drop clusters. Letters to ZhTF 79 (8), 457–459.

Fleagle, R.G., Businger, J.A., 1963. An Introduction to Atmospheric Physics. Academic Press, New York, 346 pp.

Galimov, E.M. (Ed.), 2008. Problems of Biosphere Origin and Evolution. Librokom, Moscow, 552 pp. (in Russian)

Gordienko, I.V., 2008. The History of the Earth. Geo Publishers, Novosibirsk, 293 pp. (in Russian)

Haldane, J.B.S., 1929. The origin of life. Rationalist Annual 148:3–10.

Humboldt, A., 1805. Essay sur la Géographie des Plantes (English version: Essay on the Geography of Plants, University of Chicago Press, 2009).

Ivanov, A.V., 1998. Chemistry of Natural Ice, Freezing and Non-Freezing Waters: Cryogenic Metamorphism. Dalnauka, Khabarovsk, 163 pp.

Kadomtsev, B.B., Rydnik, V.I., 1981. Waves around us. Znanie, Moscow, 152 pp. (in Russian)

Kondratieva, L.M., 2010. Ice as a component of the biosphere and a concentrator of toxic substances. Biosfera 1 (1), 397–401.

Kotlyakov, V.M., 2012. The history of global climates: evidence from deep drilling in Antarctica. Priroda, No. 5 (1161), 3–10.

Maeno, N., 1988. The Science of Ice. Mir, Moscow, 231 pp. (Russian Translation from Japanese)

Melnikov, V.P., Rogov, V.V., Kurchatova, A.N., Brushkov, A.V., Griva, G.I., 2011. Distribution of microorganizms in frozen ground. Kriosfera Zemli XV (4), 75–78.

Mendeleev, D.I., 1950. Collection of Works, 25 volumes, vol. 22: Meteorology. AN SSSR, Moscow-Leningrad, 868 pp. (in Russian)

Milanković, M., 1930. Mathematische Klimalehre und Astronomische Theorie der Klima-schwankungen (Mathematical Science of Climate and Astronomical Theory of Climate Variations). Gebrüder Borntraeger, Berlin, 176 pp.

Moiseev, N.N., 1997. Coevolution of nature and society: Ways of noosphere genesis. Ekologiya i Zhizn, No. 2–3, 4–8.

Neumayr, M., 1887–1895. Erdgeschichte (History of the Earth). Verlag des Bibliographisches Institut, Leipzig, 800 pp.

Oparin, A.I., 1968. Life, its Nature, Origin, and Evolution. Nauka, Moscow, 173 pp. (in Russian)

Parmon, V.N., 2004. Natural selection among molecules. Science First Hand 0(1), 32–41.

Pauling, L., 1935. The structure and entropy of ice and of other crystals with some randomness of atomic arrangement. J. American Chemical Society 57 (12), 2680.

Pechurkin, N.S., 1988. Energy and Life. Book Series "From a Molecule to an Organism". Nauka, Novosibirsk, 190 pp. (in Russian)

Slagoda, E.A., 2005. Micromorphological Signatures of Cryogenesis in Late Cenozoic Sediments: Implications for the History of Permafrost. Doctor Thesis (Geology & Mineralogy), IKZ SO RAN, Tyumen, 199 pp. (in Russian)

Tsyganova, E.A., Salamatin, A.N., 2006. The isotope composition and age of Vostok ice cores, Central Antarctica: Paleoclimatic interpretatiton. Materialy Glaciol. Issled., No. 100, 5–23.

Varfolomeev, S.D., Demina, O.V., Khodonov, A.A., Laptev, A.V., Nikolaev, E.N., Kononikhin, A.S., 2008. Molecules and the life, in: Problems of the Origin and Evolution of the Biosphere. Librokom, Moscow, pp. 57–78. (in Russian)

Vernadsky, V.I., 2004. The Biosphere and the Noosphere. Airis-Press, Moscow, 576 pp. (in Russian)

Wackett, L.P., Sadowsky, M.J., Newman, L.M., et al., 1994. Metabolism of polyhalogenated compounds by a genetically engineered bacterium. Nature 368, 627–629.

Wegener, A., 1929. Die Entstehung der Kontinente und Ozeane (The Origin of Continents and Oceans) Friedrich Vieweg & Sohn Akt. Ges., Braunschweig.

Yushkin, N.P., 2004. Born from Crystals? Science First Hand 0 (1), 42–54.

Zavarzin, G.A., 2004. Microbes: Keeping it going. Science First Hand 1 (2), 20–27.

Received August 10, 2014