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PHYLOSOPHICAL ISSUES OF CRYOLOGY

CRYOSOPHY: AN OUTLOOK OF THE COLD WORLD

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The outlook of the cryosphere in the present scientific community has been changing rapidly. Rather than being a danger, the sphere of ice and cold is taken as an active element of the universe, a wealth, and a source of wellbeing and new potentialities for the mankind. This is the reason for increasing recent interest to the cold world among different scientists and, on the other hand, for broadening the scope of the classical permafrost science. It is time to create a new school of thought, that of cryosophy. Cryosophy should focus on the role of cold matter in the ever changing world and on the basic properties of the cryosphere. The presented snapshot of highlights of the cryosphere from the early Universe to the life origin, which remain little discussed in the permafrost community, illustrates the urgent need in new ontological approaches.

The turn of the century has been marked in permafrost science by dramatic changes in the views of its very object. At the dawn of cryology, permafrost was treated as ill in terms of practice (see, for instance, P.I. Koloskov's preface to the book of *Sumgin* [*1927*]). That long remained the leading attitude while continuous struggle against cryogenic hazard narrowed the scope of studies and promoted the search for technological solutions rather than scientific research. It is not until the recent decade that the cryosphere has been understood to be a universal phenomenon, a matter-energy element of the Universe, a wealth, and a source of life, human wellbeing, and civilization progress. This change of values brought about new methodological approaches and, furthermore, different views of the research subject and goals.

The subject of cryology is changing as the scope of research has been expanding with diverse issues from the life origin to agriculture enhancement, from extraterrestrial missions to records of historic events. Proper understanding among scientists who work in these different fields requires updating the system of concepts by enlarging their meaning and modifying concepts, even the old ones which have withstood the test of time.

It is urgent at the moment to depart from the conventional boundaries between disciplines and to develop a new panoramic outlook of the object (cryosphere) and methods of research, taking into account the current advances in other sciences, in order to finally create a basis for cryosophy as a new ontological line in philosophy [*Melnikov, 2010*].

Cryosophy aims at understanding the role of cold matter in the evolving matter-energy interplay, as well as in the origin and maintenance of life. The new science should focus on the most general properties of the cryosphere and its basic links with other components of the Universe. The research should stem from both classical (applicable to simple physical and chemical systems) and synergetic (for complex systems, including biological ones) approaches using both the methods that yield knowledge of things and the information logistic methods which provide knowledge of knowledge [*Melnikov et al., 2005*].

Ice and its phase change – the focus of cryology – has been the subject of diverse sciences and research fields. The chart of Fig. 1 shows different aspects of ice and the roles it plays in the world.

Boxes on the two sides of the "space" axis represent the hierarchy of objects and media in which ice is the major control. This pattern corresponds to the classical approaches viewing ice as something people meet in the everyday life, the cryosphere being the best instrumentally explored sphere of the Earth. However, it is time to revise the views of ice as a superplanetary object.

The history of the Universe, since the big bang when matter just sprang out of elementary particles (protons, neutrons, and electrons), has been linked with hydrogen which, along with helium, was the first to form on cooling. 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 ever before water and life appeared on the Earth. Moreover, it will remain in the Universe even after the Sun expands and heats up, and after our Earth transforms into something like a lifeless hot planet.

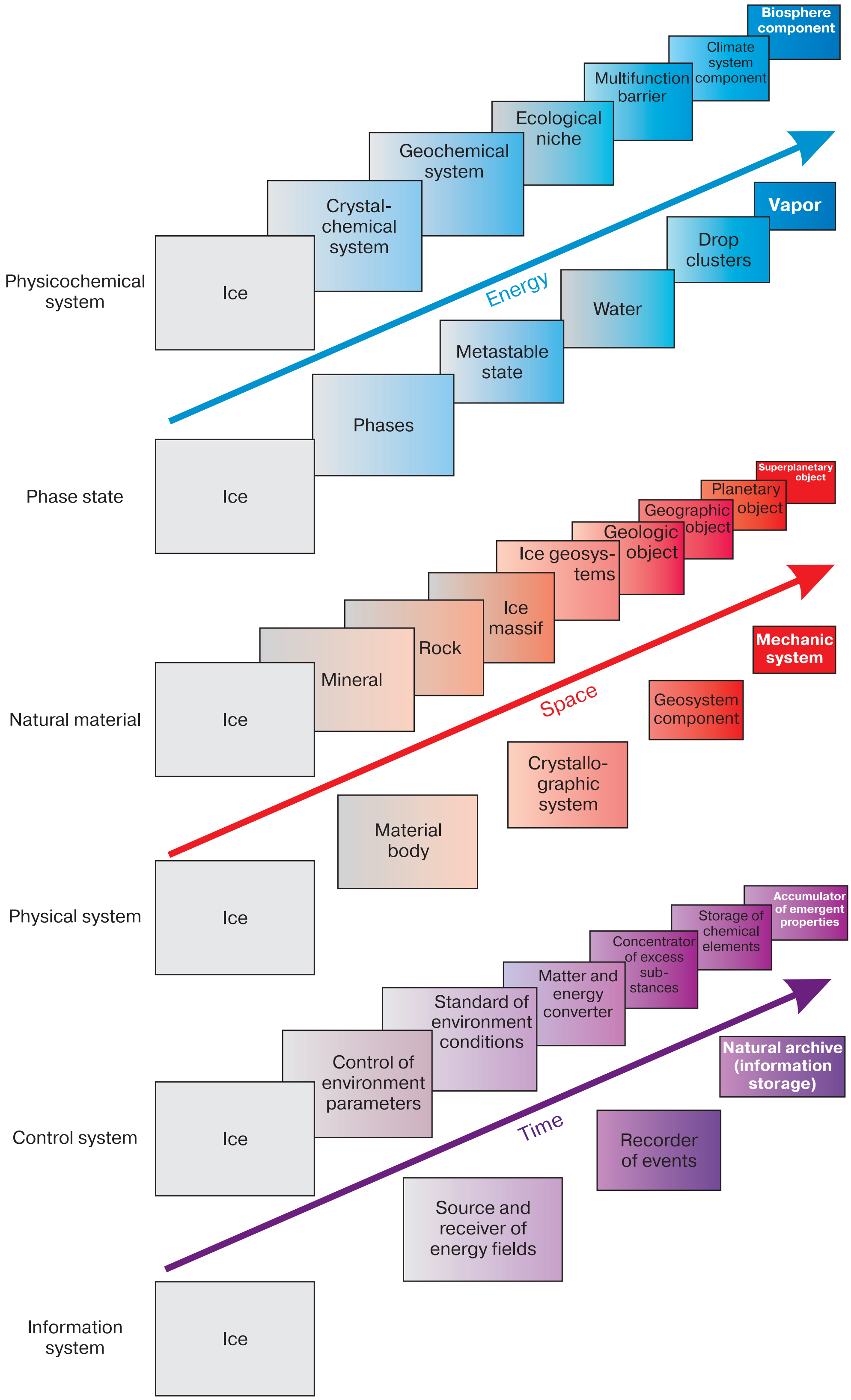

Fig. 1. Ice as a multifunction system.

The diversity of conditions on the planets and other large objects in the Solar System (distances from the Sun, orbits, year and day durations, presence or absence of atmosphere, etc.) prompts that the terrestrial cryosphere is not unique but is, instead, a common phenomenon being special though in its bioprotective ability.

The recent advances in space exploration furnish impressive evidence of cryogenic processes on the primary planets and their satellites. People are waiting for ever more wonderful things to learn against which the Earth's permafrost would not look so fascinating, but it will certainly remain of vital importance to humans and to all living beings on our home planet.

Let us turn back to our chart (Fig. 1). The "energy" axis illustrates the phase states of ice and its functions. Compared to single-state water, ice has far greater phase diversity, with its seventeen states out of which eleven are explicit. This diversity shows up in various physicochemical and biological processes, including such a common thing as precipitation: rainfall of one type, snowfall of eight types, and two mixed types of ice-water precipitation.

Ice is sometimes interpreted as a mere by-product of water transformations. What people commonly speak of are three aggregate states of water but not of ice. This is a purely subjective human attitude, as intuitively (and biologically) water seems closer to people than ice. This attitude is standard but not normal, and this is not fortuitous: the standard conditions people stand the best are those of 1 bar (1 kPa) pressure and 25 °C temperature while the normal natural conditions are, respectively, 1.01 bar and 0 °C.

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 follows a certain trend toward an ideal structure: its order increases while entropy decreases with time at a constant low temperature [*Maeno, 1988*].

Ice crystals are built uniquely of hydrogen bonds, i.e., ice can be a standard to estimate hydrogen bonds. At the same time, hydrogen bonds are indispensable in proteins, nucleic acids, or biopolymers. They have been crucial to the very life origin as all biochemical processes in living beings are associated with breaking and resuming hydrogen bonds.

The complexity of the ice structure and its off-equilibrium phase change are sufficient for self-organizing synergetic behavior and formation of stable macroscopic objects. One such object, a drop cluster, is shown in the energy scale (Fig. 1) between water and vapor. Drop clusters are stable dissipative structures in the form of ordered tiny condensate balls of the same size which appear in the gradient zone over a locally heated liquid phase [*Fedorets, 2004*]. Phenomena of this kind may be a missing link between the organic and inorganic matter.

The "time" axis (Fig. 1) presents cryogenic systems in terms of information, resources, and cybernetics. The cryosphere changes the characteristic times and rates of processes and stores records of the other terrestrial spheres, which has an intimate relation with synergetic processes and with the life origin and evolution.

A topical objective of cryology is contributing to the knowledge of geological history through studying the effect of glaciations on the evolution of the biotic and abiotic components in the crust. Till the present, permafrost scientists have dealt mainly with the Quaternary but the most interesting things apparently occurred 2–2.5 billion years earlier. It is since 2.5 Ga that the Earth has experienced repeated glacial cycles of different durations and intensities. A correlation has been discovered between the beginning and end of glacial cycles and the composition of atmosphere, especially CO_2 and sulfur [*Dobretsov, 2004*]. However, the history before 2.5 Ga likewise calls for new approaches and hypotheses. The scientific community has been split into partisans and opponents of the "hot" and "cold" models of the early Earth. The "snowball" scenario when the planet was fully covered with ice [*Kirschvink et al., 1997*] may have repeated many times, and the task of cryology is to discover traces of those periods.

It is necessary to determine the functions and physicochemical and other manifestations of ice in the early geological history to gain insights into how traces of events happening in cold times may in principle look. This may be "cryo-traceology", a special new field to concern with interaction of ice with biogenic and abiogenic components of the medium.

The cryosphere is subject to various natural cycles, this cyclicity being obviously more diverse than it is commonly thought. In cold seasons (autumn, winter, and spring in the Northern Hemisphere), circadian (diurnal) cycles become essential in cryogenic systems. The ice-water phase change that stabilizes the temperature regime for the living world occurs during a day. The yearly cyclicity is more prominent: snow and ice can keep stable for a long time creating cryogenic conditions. Note that the diurnal cycles naturally disappear in polar regions (the polar day and night are six months long), and living beings likewise adapt to these patterns (e.g., reindeer lack biological clock). Other longer-period cycles are associated with the solar activity (11- and 270-year cycles).

A more complex cyclicity shows up in glaciers. Evaporated ice molecules crystallize in clouds at the atmospheric temperature filter and precipitate as snowfall. If snow fails to melt during the warm season, the accumulated viscoplastic mixture of ice and granular snow makes up a glacier. The glacier gradually slides down by gravity into the zone of ablation where it degrades mechanically, melts, and evaporates. Thus, each glacier has its own characteristic life time controlled by climate (temperature and moisture) and geography (terrain and rock structure). The glacier cycles may have different periodicities, from several years in highlands and subpolar regions to tens of thousand years in Greenland or Antarctic. It is interesting to investigate the interaction of different cycles in systems of this kind.

The cyclic processes in the cryosphere likewise demonstrate the parentage of the cold and the life: both undergo entropy cycles at intense heat and mass exchange. The birth of a living being, as well as the formation of ice out of water and vapor, reduces entropy and produces self-organized complex systems.

It is evidently the atmosphere, with its thermal shield aggregating water molecules into ice particles, that holds back water on the Earth. This is a factor crucial to the origin of life. Any change in the Earth's cryosphere anyhow influences the evolution of the life-sustaining environment. Atmospheric ozone had formed about 400 Ma ago and let the life move from the ocean to the land [*Dobretsov, 2004*]. Judging by the vertical pattern of air-borne ozone similar to the air stratification, it is the weakness of hydrogen bonds that allows creatures to leave water for existing freely on the land (or, in the same way, to leave land for the troposphere).

Hydrogen has been critical to the energy budget of oldest biological systems [*Fedonkin, 2000*] 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 science of cryology focuses on transformations and interactions of the primary elements of hydrogen and oxygen. Cryosophy may occupy its niche in the cryosphere research through working out life evolution theories viewing the evolution beyond the limits of a specific planet. Ice, the precursor of water, dates back to the very beginning of the Universe when there appeared hydrogen and then oxygen whose aggregation and hydrogen bonding laid the basis of the animate and inanimate nature.

The origin of terrestrial life was possibly preceded by a prebiological evolution stage [*Galimov, 2001*]. According to a hypothesis by *Diakonov* [*1994*], the self-similarity of biospheric and civilization crises (acceleration of historic time) recognized in the four billion-years history of the Earth indicates that the beginning of the prebiological evolution coincided with the formation of the galactic disc about 10 Ga ago. That was exactly the time when ice appeared as a special phase offering an example of molecular interaction to all living beings.

The fact that the mean annual air temperature on the Earth long remained about the ice-water transition point appears quite natural. Ice, like water, possesses exceptional thermostatic properties which, along with its wide spread over the ground surface, allows the cryosphere to stabilize the temperature regime. Note that the heat capacity of water (4.183 kJ/kg·K) is five times the mean heat capacity of soil, and its bulk heat capacity is 3300 times that of air. The high heat capacities of water and ice (2.06 kJ/kg·K) make them the Earth's principle storage of the solar energy. The very phase change point has additional (likewise abnormal) thermal stability: specific heat of ice melting is five times as high as in gold (332 against 66.2 kJ/kg) and is higher than, say, in mercury by a factor of 28 (12 kJ/kg).

The temperature stability defines the conditions favorable for the living nature while ice acts as a bioprotector that stabilizes the parameters of the environment.

The cryology-biology union began since the earliest years of the permafrost science in the USSR. Just remember the exciting finds of mammoths or reviving insects recovered from frozen ground in the first half of the 20th century.

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, life in natural permafrost would appear a "resort" for microorganisms.

As the Vostok ice cores from Antarctica showed, 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, and 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 nonequilibrium coevolving system in which microorganisms are intrinsic components of ice or frozen rocks.

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.

A recent example of the kinship between the cold and the living comes from a discovery that bacteria (specifically, *Pseudomonas syringae*) may be responsible for most of rain and snow being ice nucleators [*Christner et al., 2008*]. Bacteria were found out to be able of traveling long distances together with clouds and cause snowfall all over the world at quite high temperature. There is nothing surprising about it, as the relatively light bacteria can act as crystallization nuclei and seeds for the new phase at the heights where rain and snow originate and where the heavier objects can never rise.

Vernadsky [*2001*] wrote that the living matter had a strong control over the formation and regulation of geochemistry and physics of the biosphere, atmosphere, and the hydrosphere. The cryosphere, in turn, may be a link between the Earth and the life: first it cherished the life and then offered an example of maintaining suitable life conditions.

There are diverse processes in which ice or water near the phase change point are crucial. They show up in obvious or paradoxical ways. The various facts make up a mosaic, a sort of a puzzle the clue being the kinship between ice and life and their ability to form composite objects and stable systems with new emergent properties.

Cryology has been assimilating ever more terminology uncommon to a classical applied science, such as diversity, stability, complexity, or emergent behavior; systems are brought together into meta-systems, and simple models give way to hierarchies of models. Thereby it becomes a multidisciplinary and actual science, with a focus at urgent practical needs. As the subject of study has been increasingly expanding, the methods available in cryology can no longer lead to the wanted ends.

Today, when knowledge is growing rapidly and various sciences are interfingering while the education principles and position of a scientist in the world are changing, cryosophy should become the cryology of the future, should broaden the scope of the latter, develop a high-performance methodology, and provide guidelines for the prospects and expected results of research.

Cryosophy should maintain the interest to cryogenic processes and phenomena, to the "short circuit" between the life and the cold, in classical permafrost scientists, as well as in those engaged in biophysics, biology, meteorology, planetary research, all those who deal with problems new to the scientific community. As soon as results from other sciences have received new interpretations in terms of cryology and have been projected onto the sphere of cold, cryologists themselves will no longer rediscover, with enthusiasm of neophytes, the things known for ages.

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