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CONCEPTUAL PRINCIPLES OF CRYOLOGY

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EVOLUTION OF THE UNDERSTANDING OF COLD AND POSSIBLE PATHS OF ITS DEVELOPMENT IN EARTH SCIENCES

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In further development of the ideas elucidated in the authors' previous works this paper discusses the problems of the perception of phenomena yielded by cold, analyzes the evolution of our understanding of them and dissects questions of terminology that reflects the manifestations of cryodiversity. The possibility of analyzing cryodiversity as an aggregate of the objects within the frame of cryogenic geosystems of different types and ranks is explored. A scheme of interactions between the given objects as elements of such geosystems is proposed, and examples of the application of such an analysis for the assessment of cryogenic environments are provided.

Cryodiversity, cryogenic geosystems, phenomena yielded by cold

INTRODUCTION

The uniqueness of the environment of the Earth's spheres is by virtue of cold. Understanding this and uncovering the peculiarities of the processes that exist by virtue of cold is a topical challenge, especially for Arctic and Subarctic regions where active natural resource extraction is taking place alongside native peoples' traditional activity. The need to adjust data based on general scientific approaches arises more and more frequently: extensive material on the phenomena yielded by cold has been collected, it is in need of deeper analysis, and handling it from past positions often prevents the advance to new conceptual levels, as well as the resolution of terminological and other contradictions. Paradoxically, the very concept of "cold", so frequently used in geosciences, still has no clear definition, although the conditions for the rectification of its role already exist [*Melnikov et al., 2010, 2013; Sheinkman and Melnikov, 2014*].

Questions regarding the comprehension of phenomena yielded by cold were raised in the 1980s by the well-known geocryologist S.S. Gasanov [*1981, 1984*] as a response to the discussion on the introduction of system analysis and geosystem theory to geosciences [*Sochava, 1978*]. This was, essentially, the first attempt to adjust the paradigms of the methodology of studying permafrost, but a decline in interest toward such research followed. It took 30 years of accumulating multidisciplinary knowledge about cryogenic phenomena to spark this interest again, which, in turn, created a need for new adjustments and deepening of the conceptual apparatus. Leaning on developments [*Gasanov, 1981, 1984*] and rethinking terminology based on the Greek word "cryos – χρυος" (meaning frost, cold and ice) the authors explore phenomena yielded by cold and their interactions from various points of view, treating first and foremost the discovery of the genetic specifics of these phenomena as the most important. The authors hope that such an approach will contribute to the topical goal of comprehending, using and explaining the patterns of cryogenic resource formation. A complete analysis of the issue on hand requires the presentation of the results in a more voluminous work, but its main features are nonetheless highlighted within this article.

History of the formation and evolution of concepts denoting cold

Researchers broadly using the term "cold" in geosciences have not yet come to an agreement regarding its definition, which leads to an obvious uncertainty about conceptual approaches to studied phenomena and spawns discrepancies. Primarily terminological ones because scientists must clarify when expressing their views within which conceptual field's and terminological resource's framework they are handling data. Especially because cold world research often locks up within one sphere of knowledge, and information that can realistically be obtained only at the junction of sciences, drawing on each of their potentials, is lost.

As S.S. Gasanov pointed out [*1984*], all of this is a consequence of the lack of a possibility to synthesize knowledge without stepping over the boundaries of a given discipline, which, essentially, explains the reignited discussion on comprehending the cold world. On the one hand, science is beginning to see branches that can claim the role of independent disciplines, but on the other hand, the pursuit of holistic knowledge is objective, which defines the need for ideas that resist the most persistent tendency in science – its differentiation. This is what makes the suggestion to bring the comprehension of cold onto the level of a new direction in the philosophy of science – cryosophy – relevant [*Melnikov et al., 2013*]. Especially because the combination of sophistic knowledge [*Epshtein, 2001*] and conceptual knowledge has been used for a long time. Theosophy, which aimed to make the general system of knowledge from the position of religions universal, emerged in classical antiquity. In new and newest times various directions emerged in geosophy – attempts at a philosophical understanding of geosciences, – later of biosophy, which aims to comprehend life processes, and then other sophistic disciplines appeared [*Bychikhina, 1992; Epshtein, 2001; Bystrov et al., 2016*].

The main challenge in our case is related to cold as a phenomenon having been historically approached by different sciences and on different spatial and temporal levels, which has spawned stereotypes in the perception of cold from the standpoint of specific disciplines that typically study not cold itself, but some type of its manifestation. And yet sciences that had later been combined by cryology were founded much earlier than cryology, which is evidenced in relevant publications. For example, in the works of Isaac Newton ("Scale of the Degrees of Heat"), Mikhail Lomonosov ("On Origins of Heat and Cold") and Leonhard Euler ("On the Nature of Heat"), published in 1701, 1744 and 1752, respectively. As a result, having failed to clearly define the concept of cold, geosciences chose ice to carry the torch as the paramount symbol of cold, and disciplines were created with the intent of directly studying ice in its various forms and environments, rather than the cold on which its development depends. The content and terminology of these disciplines evolved in much the same way, leading to future discrepancies in the understanding of phenomena yielded by cold.

Because researchers did not give a definition to the concept of cold when utilizing it, it remains an anthroposensory phenomenon (determined by perception by humans of the cold around them). But inhabitants of regions where the environment is characterized by lengthy periods of low subzero temperatures consider even slightly positive temperatures warm, whereas inhabitants of tropical regions will call their surroundings cold at just +10 °C. Science, however, requires strict definitions, and because the concept of cold assumes various states of the environment, with respect to natural phenomena it must carry physical characteristics that give it a corresponding status. But cold as a concept has not existed in physics historically: neither the term "cold" nor the term "warmth" appear in physics textbooks. Physics makes use of the terms "heat" and "heat energy". Heat is a form of motion of the particles comprising a physical body (atoms, etc.), referred to as their heat motion [*Physical Encyclopedia, 1998, p. 748*]; it is measured by the value quantity of heat and associated with heat energy conducted or received by bodies and environments during heat transfer. The term "heat" is, of course, present in daily usage, and it is associated with atomic and molecular movement in the environment. From this point of view cold – the antipode of heat – is a phenomenon that reflects a decrease in atomic and molecular movement in the environment, and this approach could become the foundation for bringing order to the concepts from the standpoint of both anthroposensory perception and physics. Nonetheless, even a provisional description has not been constructed for cold, other than the occasional mention of cold as the state of an environment lacking heat.

As a result, when characterizing one phenomenon or another using the term "cold", scientists are not always trying to convey the same meaning and, consequently, do not interpret it in the same way. Let us look again at physics: using "heat" as a measure of energy that is being transferred from one body to another in the process of their heating and cooling, physics uses a clearly defined magnitude as an indicator of cooling and heating of bodies and environments – temperature. Essentially, leaving anthroposensory perception for non-academic use, cold could be defined based on the temperature conditions of its environment, an understanding of the phenomena it may encompass could be reached and what natural indicators could characterize its status could be determined. In other words, cold could have long been expressed as a state of the environment in which the environment's loss of thermal energy will be defined by clear criteria. It would then be possible to distinguish the disciplines for which these phenomena will become a subject of research. This was not done for objective reasons that make the formation of a universal approach challenging.

Many sciences' beginnings go back to classical antiquity, where they fixated in Latin and Greek, which became the foundation of scientific lexicon. Peoples that inhabited the Mediterranean signified the characteristics of their colder environments with words related to the situation in which water freezes. They viewed even short-time freezing as a major cooling in their surroundings, and significant cold began to be associated with the appearance of snow and ice using suitable words. Recall that in Latin these words are *nivalis* – snowy, icy, as well as cold as snow; *glacies* – ice, but also the environments in which ice forms – cold, frost; *glacialis* – icy or frosty – cold as ice [*Sheinkman and Melnikov, 2014*]. The Ancient

Greek language uses the aforementioned word *cryos* (χρυος) similarly: it means ice, but at the same time cold and frost [*Dvoretskiy, 1958, 1986*]. The same occurs in other Mediterranean languages. For example, in Hebrew the word *kor* (קור), consonant with the Greek *cryos* (χρυος), signifies cold, and its derivative *kerach* (קרח) translates as ice.

Terminology related to glaciers started to form using this baggage. In O. Saussure's work published at the end of the 18th century, "Travels in the Alps", the basics of glacial science with terms based on Latin meanings of the word *"ice"* were laid down, and this science was called glaciology. But other icy bodies that were not in the composition of glaciers were left aside for a long time, even though permafrost ice was noted up to a 30-meter depth in Yakutsk a century earlier during the digging of a well by the Cossack Yakov Svetogorov in 1685–1686, as was stated in the Yakut voivode Matvei Krovkov's report [*Kamenskii, 2007*]. Russian pioneers knew about permafrost ice for a long time, but European scientists did not acknowledge these data until Alexander von Middendorff and later Alexander von Humboldt shed light on their existence in European publishing in the middle of the 19th century. The becoming of the science concerning the hydrosphere's snows and ice occurred even later – in the first half of the 20th century, and only by that time the diversity of ice on Earth in all of its spheres stopped being questioned. A number of researchers suggested attributing all kinds of ice to the objects of glaciology, basing their idea on the potential coverage of ice phenomena by the Latin word *glacies*. But the majority of scientists consider glaciology a science of glaciers, and so clarifications ensued: glaciology in the broader sense is the science of ice in the general sense and the science of glaciers in the narrower sense [*Stamp, 1975; Bates and Jackson, 1984; Kotlyakov, 1984*]. This gave rise to discrepancies, and attempts were made to introduce clearer terminology. Based on the meaning of the Greek word *cryos* (χρυος) in the meaning of "ice" it was proposed to name the science of natural ice *cryology* and the entire ice sphere of the Earth – the cryosphere [*Dobrowolski, 1923*]. However, the becoming of the science of permafrost introduced adjustments. Its beginnings were described in M.I. Sumgin's work [*1927*], and, with time, the cryosphere began to include all the Earth's spheres where the environment has a subzero temperature, and cryology began to take the shape of a science focusing on the cryosphere [*Tolstikhin, 1974*]. The proposal to use the Greek word παγος (*pagos*), also meaning cold (creating the science *pagology* and terminology that would differ from that proposed in [*Dobrowolski, 1923*]), did not set in.

Recall that the broadening of terminology based on the word *cryos* (χρυος) took place relatively recently. Only in 1966 N.I. Tolstikhin gave a new definition to cryology as a discipline studying the cryosphere – a specific sphere of Earth or other planets [*Tolstikhin, 1974*]. Suggesting to consider cryology a universal science of the cold world – not just of Earth, but of other planets, as well – N.I. Tolstikhin noted with regret that at the time of his proposal it did not actualize [*Tolstikhin, 1974, p. 10*]. He was of the opinion that at that time there were no universally accepted definitions and concepts of the cryosphere and cryology. It must be stated that after half a century there is still discussion on the subject, all the more so because a corresponding discussion has not taken place since the time the issues were last raised by E.A. Vtyurina and B.I. Vtyurin [*1982*]. At the same time, 1970 can be considered the starting point of the becoming of Earth cryology when, despite the yet unstable perception of the new science, the Scientific Council of Earth Cryology was established under the Department of Oceanology, Atmospheric Physics and Geography of the Academy of Sciences of the Soviet Union.

It is extremely important to overcome discrepancies. Phenomena yielded by cold are inseverably connected, and the underreporting of any of the elements of a system definable by cold only because they are the object of an adjacent science's studies leads to a significant distortion of the assessment of the environment. What helps overcome this issue is considering objects from the perspective of cryodiversity: it combines phenomena yielded by cold while taking into account that each of them, carrying dissimilar and non-recurring traits, brings a unique volume of information [*Melnikov et al., 2013; Sheinkman and Melnikov, 2014*]. Using this information, the classification of the cryosphere's objects can be rationally perfected, making it a convenient tool for organizing knowledge on the subject. As B.I. Vtyurin [*1988*] wrote, we face a branch of knowledge requiring organization, as it is still vulnerable in its not always definite terminology and lack of a clear system of particular concepts. These words are quite relevant, so, based on the semantics and etymology of terms that form the established scientific lexicon, as the authors believe, organization must first touch the content of the concepts of "cold" and "cold world" and the perfection of classification of objects of the cryosphere by genetic features. They are the ones that form the base for recognizing the complex interrelated phenomena yielded by cold. Actualizing this is possible through a systemic approach, tying the cryosphere's objects to specific spheres of Earth, analyzing the origin of these objects and revealing the patterns of their development in their environments.

Cryodiversity and the transition to cryogenic systems

First of all, we should note what the authors assume under the terms "cold" and "cold world", as of yet perceived mainly rhetorically: they are not in the dictionaries. B.I. Vtyurin was the first to use the word combination "world of cold" [*Vtyurin, 1988*], titling a translation of a work he was editing this way [*Washburn, 1979*] (*Geocryology*) and noting the combination of objects of geocryology as of Earth cryology, which is, essentially, correct because the Greek root *ge* – γη means *Earth*. The word combination "the world of ice" as related to the ice objects of our planet was used earlier by D. Dyson in the title of his book [*Dyson, 1962*]. But no clarification of terms was provided, and in both cases the subject was the field of subzero temperature, which does not include ice-like gas hydrates and does not emphasize that cold is a state of the environment. The authors propose the following clarification: *cold is the condition of a specific environment in which its loss of heat energy leads to a decrease in the temperature of this environment prior to the formation in it under normal circumstances of water ice or a similar gas hydrate under high pressure*. The concept of cold, obtaining a physical essence, is then determined by the condition of Earth's environments at the temperature of the crystallization of water (0 °C under normal circumstances) or an ice-like gas hydrate (~5 °C at great depths) and to maximally low values (in Earth's conditions around –90 °C). Similarly to P.A. Shumskiy's suggestion [*1955*] to assess glacial processes through glaciation energy, a parameter such as cold energy can be introduced – an equivalent of heat energy required to increase the temperature of a cold environment to the point of the melting of ice (or a gas hydrate) and further for its melting.

The introduction of these concepts would help in the organization of the system of views on phenomena yielded by cold, which in this case can be combined, removing discrepancies, under the term *cold world*. The concept "world" combines the entirety of all forms of matter in the space of Earth and the cosmos, and *cold world* then emerges, taking a clear shape, as an environment the properties of which are determined by cold. The authors believe that in the terminology that reflects it, in an effort to avoid discrepancies, it is necessary to use the root *cryos* (χρυος) as meaning *cold*, and the term "*cryogenic*" meaning *yielded by cold*. The term "*cryogenesis*" should then combine (semantically this is literally *yielded by cold*) all processes definable by cold, without being restricted to those that occur in rocks at subzero temperature, as was thought when only this side of cryogenesis was emphasized [*Tyutyunov, 1960*]. Following the rules of semantics, permafrost science as a science of frozen rock must not be correlated with geocryology in general but considered its component, identifying it with Earth cryology – a science the object of which is the entire cold world of our planet.

The diversity of all natural phenomena (including cryodiversity) is organized by systematics the goal of which is the development of their classifications: the construction of hierarchies with subordinate taxons – those elements of classification that combine objects based on their common properties and features and correlate on the principal of the highest level of their organization to the lowest. The correlation when one taxon has been divided into lower-level taxons and is, at the same time, part of a higher taxon, is what makes the taxonomic hierarchy, the individual levels of which are taxonomic ranks [*Shatalkin, 2012*]. In geosciences the taxonomic ranks are usually identified by their coverage of one of its parts [*Kotlyakov, 1984; Kotlyakov and Komarova, 2012*], and geosystems make up a row in their organization: from the highest, planetary level to the lowest, elementary level. The authors will use this hierarchy.

Analyzing the tendencies of cryology, S.S. Gasanov wrote that "one of the effective methods of stimulating integrative tendencies is interdisciplinary synthesis, which in the most general sense means overcoming empiricism in the process of obtaining new knowledge, bringing all the uncontrollable multiformity of the objects of the studied reality to a uniform foundation..." [*1984, p. 4*]. The unification of objects of cryodiversity within the frame of cryogenic geosystems became one of the paths to such organization of knowledge about the world of cold [*Melnikov et al., 2010; Sheinkman, 2012; Sheinkman and Melnikov, 2014*]. By identifying the genetic features intrinsic only to those objects it becomes possible to highlight the entireties of all phenomena yielded by cold and phenomena naturally unified by it in the margin of cryodiversity and to identify specific hierarchies among them. Then it would be possible to identify their affiliation with systems of particular types and on a corresponding level of organization, thus overcoming discrepancies justified historically by differentiation among the branches of cryology. The reorganization of the conceptual field of cryological knowledge and ordering of its terminological apparatus according to accumulated experience and new knowledge has, one way or another, ripened: the authors propose a possible solution to the development of ideas set out in [*Melnikov et al., 2010; Sheinkman and Melnikov, 2014*]. Its point is to use the principles of a systemic approach to establish a hierarchical subordination of cold world phenomena based on systematization based on genetic features, thus creating clear schemes of interrelations of the cryosphere's objects. These objects in a corresponding hierarchy become elements of specific cryogenic geosystems, and their classification features can then be used as a diagnostic tool in cryological situations. This method of solving the problems at hand is constructive, and the conceptual discrepancies that have accumulated to date define its purpose.

Initially the science of geosystems was meant for studying landscapes [*Sochava, 1978*], but then its approaches were applied widely in geosciences. The classic definition of a system is a set of interacting elements [*Bertalanfi, 1969*]. The cryogenic geosystem is an entirety, distinguishable as a result of the interaction of phenomena yielded by cold. Their organization on a planetary level is the geosystem of Earth's cryosphere (Fig. 1). On a global level it is the combination of cryogenic systems with the frame of its main spheres: the atmosphere, the lithosphere, the hydrosphere and the glaciosphere (the latter is an independent snow-ice sphere, as in [*Kotlyakov, 1984; Kotlyakov and Komarova, 2012*]. Consequently, they include: cryoatmogenic, cryolithogenic, cryohydrogenic and the dyad of cryogenic-glacial + cryogenic-nival systems (see below). They combine systems of a lower rank – regional, local and others, geosystems will be on the lowest level, which, depending on their genetic ties, can be conveniently distinguished as elementary – these are systems of individual glaciers, icings, polygonal ice wedges (PIW), etc. Such a division and volume of taxons are, of course, contingent, a number of them can be distinguished on the "global – elementary levels" line; everything depends on the goals of the research.

Only the boundaries of global organization level geosystems or specifically highlighted lower-rank systems can realistically be clearly defined. The development of a detailed classification for cryogenic systems, as was done for landscapes [*Sochava, 1978*], is a task for the future. In our case the subject is cryodiversity in various environments, and even presenting all taxons in the classification offered in this paper is impossible.

The flows of matter and energy in various cryogenic systems can intersect: for example, atmospheric surface layers are part not only of cryoatmogenic systems, but there is not much point in highlighting complex intermediary taxons – for example, atmocryolithogenic ones. In this case the solution lies in unifying cryogenic objects in compliance with the principle of dominant traits and manipulating them on a genetic basis, which is reflected in the suggested classification. As an example, let us look at geosystems related to groundwater in the cryolithozone. They are called cryohydrogeological in the work [*Alexeev, 2005*], but this name loses the point of the phenomenon as of one yielded by cold: the root *logos* – λόγος as a base points to a specific science studying an object, not to its genesis. In this case a better term would be hydrogeogenic [*Romanovskiy, 1993*], with the prefix *cryo* geosystems will be cryohydrogeogenic. These systems form at the junction of the lithosphere and other spheres, but their genetic dominant trait is the formation of substances in the composition of the cryolithozone. Covering them along with other taxons that combine its elements should, essentially, be up to a subdivision of cryolithogenic systems.

Nonetheless cryohydrogeogenesis yields various objects, including terrestrial ones – icing, a product of the migration of water from taliks in rock thickness with positive temperature to regions of negative temperature on the surface. The solution, as we see it, is the following: highlighting subdivisions that encompass specific objects in the composition of cryolithogenic systems. First, intra-ground systems, when the ground as a complex of rocks plays the role of, for example, a local system that holds elementary systems of injection ice and segregated ice conjugate with it; second, proper ground systems, when this complex itself serves as an object and is viewed as a separate system. Icings that are factually extra-soil cryohydrogeogenic objects will take a special place. For this it is necessary to separately distinguish among cryohydrogeogenic systems taxons of icy intra-ground systems with underground ice and off-ground icing sys-

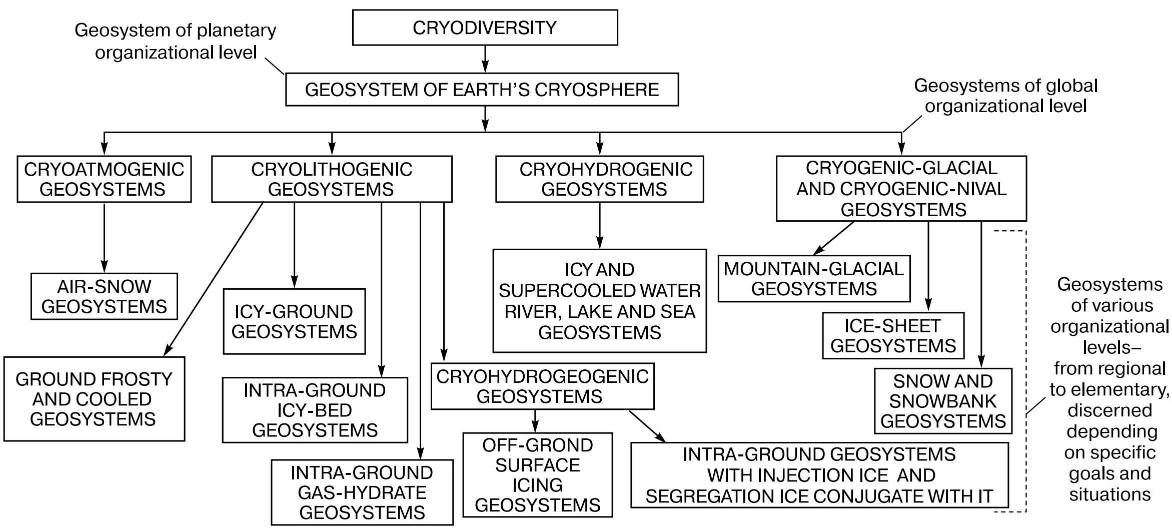

Fig. 1. Classification of cryogenic geosystems based on genetic traits (explained in the text).

tems, determining their rank depending on the situation.

The attitude toward combining the ice of snow genesis is also ambiguous. Snow, its starting substance, is the product of atmospheric cryogenesis. Snowbanks receive a certain cold energy (including potential phase transition costs) initially in the atmosphere, and because of this collected snow can exist for some time even on thawed rock. Under circumstances of replenishing cold energy, as it accumulates, snow transforms on the earth surface during sedimentary-metamorphic processes (ice formation processes are described after [*Shumskiy, 1955*]), as a result geological bodies in the form of snowbanks and glaciers can form. The challenge lies in the fact that the science describing them emerged earlier than other branches of cryology, and persistent stereotypes appeared – in compliance with them it is odd to view these elements of the cryosphere as *cryogenic* objects, *yielded by cold*. Even in the recently published dictionary [*Kotlyakov and Komarova, 2012*] cryogenesis is habitually viewed from the perspective of permafrost processes, although the geological bodies that form from a snow mass are also manifestations of cryogenesis. Especially because other forms of earth surface glaciation consist of snow and ice: the most prominent of these is the above-mentioned icing that contains large volumes of ice. Sedimentary-metamorphic transformation of snow also takes place on top of them, but it does not prevail. The main process here is congelation ice formation, and, what is important, its role is great on the glaciers of Eastern Siberia, where icings located below glaciers are frequently comparable to them in size. All of this highlights the multiformity of the manifestations of cryogenesis.

Essentially, nival and glacial formations shape a specific layer of the lithosphere and should be considered part of cryolithogenic geosystems. But this approach (it was proposed in [*Sheinkman and Melnikov, 2014*] did not receive support – the tendency to view snow ice as a component of a separate sphere of Earth is strong. Considering this, for the further development of ideas [*Sheinkman and Melnikov, 2014*] the authors propose, leaving the unification of the ice of snow genesis within the frames of the glaciosphere, to give it a new meaning, noting that specific systems yielded by cold form the glaciosphere and reflecting this in the name. With the unification of glaciers these will be cryogenic-glacial systems (CGS). Because a glacier, as concisely defined by P.A. Shumskiy [*1964*], "is a flow of ice of atmospheric origin", the clarifying term "glacial" will in this case demonstrate that we mean cryogenic systems whose flows of ice are the dominating element which first emerged from a snow mass. If snow formations that have not yet transformed into flows of ice prevail in the composition of systems, the habitual term "*nival*" will be added to the word "cryogenic" for these objects, i.e., then the subject will be *cryogenic-nival* systems (Fig. 1). The term "*nival-glacial systems*" used in glaciology demonstrates their affiliation with the cryosphere, but reflects an essentially substantial composition of ice bodies and does not carry the weight of a specifically cryogenic – yielded by cold – phenomenon, so it is not suitable in this case.

It is very important to clearly define dominant traits in geosystems of a regional rank. Encompassing large regions of Earth and having a set of specific properties, they require thorough analysis of the flows of their matter and energy, otherwise assessment of the condition of the systems will be distorted. Thus, through analysis of the regional CGS of Western Siberia in [*Sheinkman and Melnikov, 2014*] it was demonstrated that strictly specific cold energy and cold matter are fed to the entry of the system, providing the development of only mountain-glacial systems even in the coldest epochs of the Quaternary. At the same time, occasionally the ice cover systems proposed here are the result of incorrect substitutions of other (unusual for Siberia) parameters of European CGS into their entry. At the same time, if the given CGS is assessed now, it will be the combination of only several dozen small glaciers in local systems of its mountain framing. But if the CGS of the modern Arctic island area of a regional level is considered, it will be the combination of ice cover systems in whose composition even the smallest glacier of a cover nature (for example, an ice dome taken into consideration as an elementary system) will be larger in ice matter volume and occupied area than all the CGS objects of Western Siberia.

As such, the classification (Fig. 1) reflects the principle that all objects yielded by cold are, on the one hand, clearly identifiable as elements of cryodiversity that unifies all their multiformity. On the other hand, they clearly stand out within the frame of certain cryogenic systems, which can serve as an instrument for analysis of cryogenic settings.

Examples of applying the proposed approach in debatable assessments of cryogenic environments

The proposed approach, at the basis of which lies analysis of cryogenic geosystems based on genetic traits, allows to eliminate discrepancies first of all in situations when the patterns of formation of one type of system are carried over to systems of other geneses without making due adjustments. This especially concerns systems of a regional rank, the elements of which are important to analyze along with an assessment of genesis, differentiating between systems in a "warm–cold" format [*Sheinkman and Melnikov, 2014*]. The incorrectness of carrying over characteristics of European systems to Siberian objects is mentioned above: such discrepancies in the interpretation of cryogenic phenomena lead to distortion in the assessment of environments brought on by phenomena yielded by cold. We will note other distinctive examples of incorrect carryover of the properties of certain types of geosystems to differing types.

Frequently without due adjustments individual traits of the elements of low-rank systems are carried over to different, in terms of formation conditions, but seemingly similar objects, and then to the characteristics of higher-ranking systems. Thus the polygonal wedge structures (PWS) in the Nadym area with distinctive features of pseudomorphs after PIW [*Sheinkman et al., 2017, 2019*] are marked in [*Zykina et al., 2017*] as primary sandy wedges (PSW), an element of systems found only in extremely cold and dry regions of Antarctica. The foundation is the PWS described in the work of [*Zykina et al., 2017*] – narrow (~2.5 m vertically and ~0.5 m wide) and with a predominantly sandy body. At the same time, it is overlooked that even in the coldest Sartan cryochrone the Nadym area and adjacent districts were PIW, not PSW, area [*Critsuck, 2010; Shpolyanskaya, 2015; Streletskaya et al., 2015*]. For comparison, the north of Yakutia, renowned for its very cold and dry conditions (precipitation 250 mm/year, average annual air temperature approximately −15 °C) nonetheless supplies the development of PIW and sandy-ice wedges (SIW), not PSW [*Dereviagin et al., 2007*]. Using any models of air temperature decrease and precipitation [*Shpolyanskaya, 2015; Streletskaya et al., 2015*], the parameters of such conditions are extreme to Nadym area cryochrones, where the average annual air temperature with twice the precipitation is currently approximately 10 °C higher than in northern Yakutia (in the 1980s it was approximately −6 °C, today it nears −3 °C). As such, PWS are presented here as clearly expressed, secondarily filled forms of wedge-shaped bodies nested into each other, characteristic for the Nadym area – pseudomorphs after PIW [*Sheinkman et al., 2017, 2019*]. Among them are found PWS not only half a meter wide (as noted in [*Zykina et al., 2017*]), but also several meters wide. At the same time, the series of wedges are edged by clearly expressed hydromorphic paleosols (Fig. 2) [*Sheinkman et al., 2019*], which is impossible in the case of Antarctic inland systems in the composition of which there are only germinal soils [*Abramov et al., 2011*].

PSW are revealed only in the cold desert of the McMurdo Dry Valleys of Antarctica and were first described as sandy wedges nested in coarse-grained sediments [*Péwé, 1959*]. They develop under negative (throughout the year) air temperatures (average annual air temperatures are −20...−25 °C) and many-year absence of seasonal thawing and precipitation.

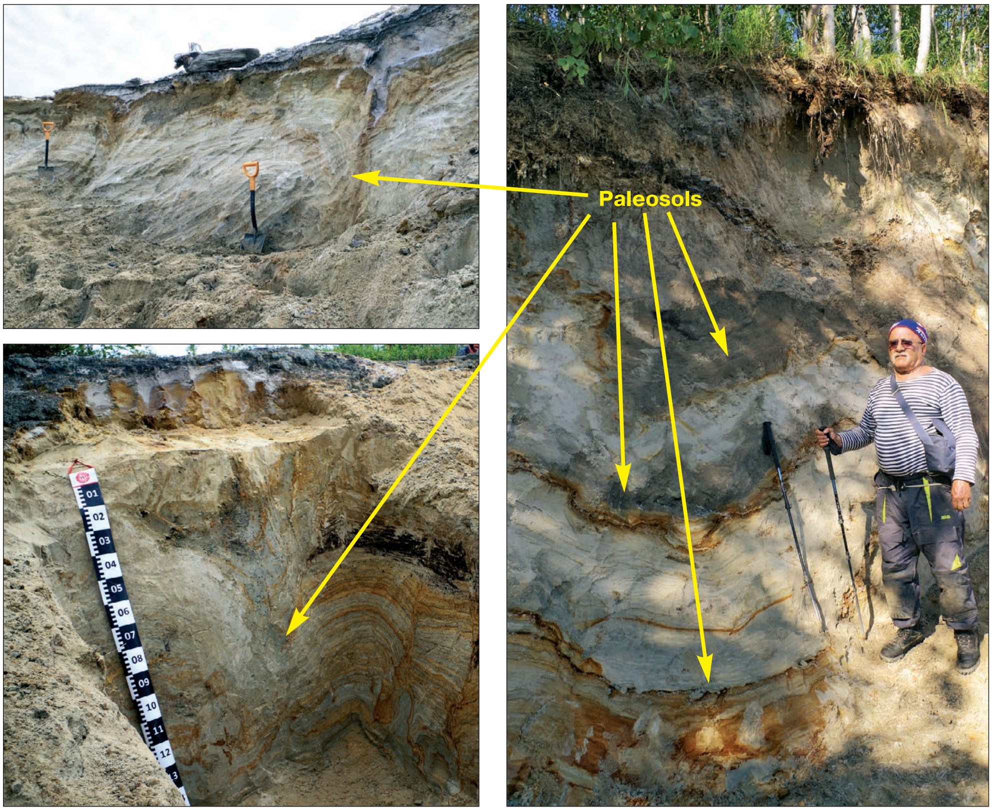

Fig. 2. Varied structure and configuration of Sartan pseudomorphs after polygonal ice in the upper part of 15–20-meter terraces in the Nadym River basin, Nadym town surrounding area.

Photo by V.S. Sheinkman.

Surface layers under such conditions dry out due to sublimation, blowout, not being held together by ice, and, as a result, the permafrost roof matches the ancient surface [*Murton et al., 2000; Abramov et al., 2011*]. Without freezing water, small PWS form: 0.3–3 m (1–10 ft) vertically, 0.08–1.2 m (0.25–4 ft) in width; their growth (0.4–1.6 mm/year) continues due to their being cut by new, long open fissures 0.3–0.9 m (1–3 ft) in depth and ~6 mm (0.25 inch) in width until they reach equilibrium with the resistance of the accommodating rock [*Péwé, 1959; Black, 1973, 1976*]. Sand that is moved by the wind fills the fissures and is gradually cemented by sublimation ice [*Raffi et al., 2004*]. Similar to them, but only outwardly, are only the individual PWS of the Nadym area, close in size to their modern representatives in the Transbaikal region, with which other parallels can be drawn. However, in the work of [*Zykina et al., 2017*], an additional argument for distinguishing PSW in the Nadym area is the activity of eolian processes. But they are usual not only in cold deserts. Under conditions of low temperature permafrost its windborne movement is not infrequent in valleys with sandy constrative alluvium.

The tukulans of Yakutia are known, as is the "Peski" stow in the Transbaikal region, where a hydrogeogenic (as in [*Romanovskiy, 1993*]) talik is developed in the Charskaya Hollow, and wind easily moves sand that is unconstrained by ice, forming dunes. But in other parts of the hollow the sandy thickness is in a frozen state and is broken by PWS [*Sheinkman and Melnikov, 2014*], which are analogous in size to those which existed in the Sartan epoch in the Nadym area. Dunes are also frequent there – both buried old ones and those that form today – that block modern Podzol soils under which Sartan pseudomorphs after PIW are clearly visible (Fig. 3). But there are no signs of deflation of surface layers to the point of exposure of PWS as in Antarctica – this is not possible under the circumstances of a past tundra [*Shpolyanskaya, 2015; Streletskaya et al., 2015*]. Sometimes the open network of PWS observed on the surface of this terrain is the result (as we have revealed) of the cutting off of the top layer of sand for construction, which is usually observed near quarries and road embankments (Fig. 3). The PWS heads that are then exposed are slightly convex, as more resistant to denudation, their substrate is held together by salts from meltwater and soils. It is important to add that fine sediments over the pseudomorphs outwardly resemble integumentary loam, which is usually accepted as a factor of active eolian influence. But the

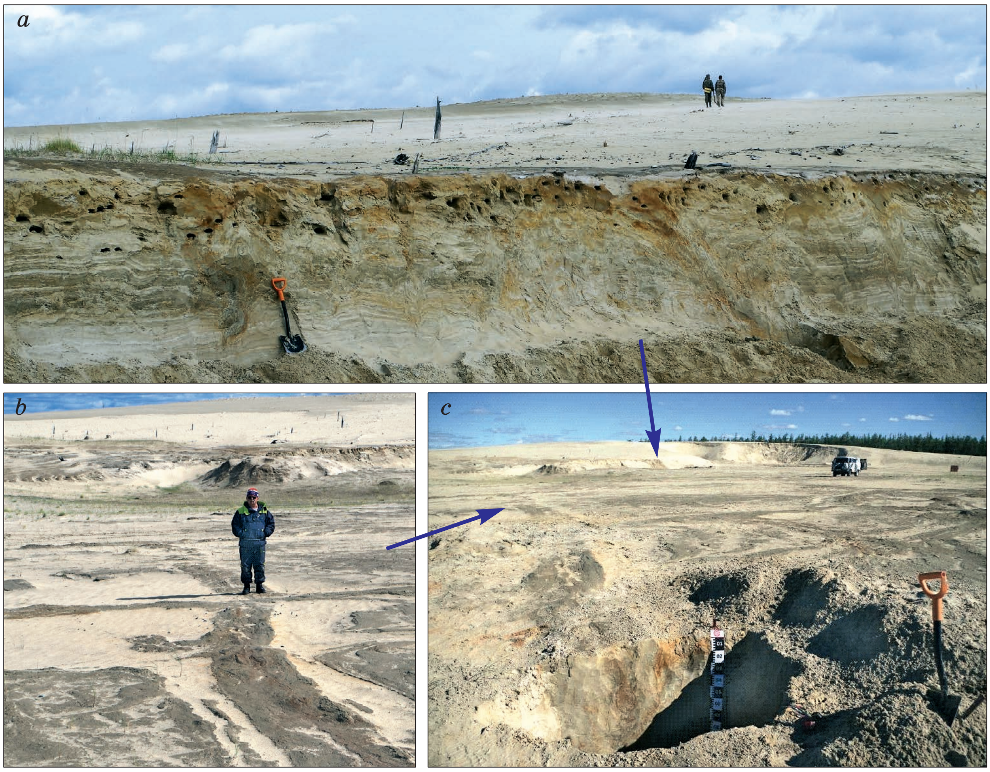

Fig. 3. Quarry 23 km southeast of Nadym Airport (65°35′ N, 72°96′ E).

a – Quarry section preparation with a network of pseudomorphs after polygonal ice wedges covered by floodplain sediments and modern Podzol; *b* – crossing of lines of cut off heads of the pseudomorphs at the bottom of the quarry; *c* – a pit with the cut off head of the Sartan pseudomorphs after polygonal wedge ice perpendicular to its length. In the background of all the photos are dunes overlapping untouched surface with modern Podzol at the bottom of the quarry. Photo by V.S. Sheinkman.

micromorphological analysis completed by Professor S.N. Sedov showed that these are floodplain sediments: relics of diatoms, sponge spicules and other freshwater organisms, as well as micro-lamination with remains of organics along layers and gleization. All these traces of the presence of water during sediment formation confirm the genesis of PWS as of pseudomorphs after PIW.

As we see, taking external characteristics of elementary geosystems that are not intrinsic to Western Siberia and carrying them over to higher-level systems led to an incorrect conclusion about the development of geosystems resembling interantarctic ones in the region's past. Also incorrect was carrying over ice cover CGS characteristics [*Sheinkman and Melnikov, 2014*].

Further we will note the icy-debris flows which have been the subject of active discussion lately due to their being used as an indicator of climate change. The problem here is also in an incorrect substitution of parameters from one type of geosystems into the entry to systems of other types and ranks. Ground and surface debris material movement is frequent in permafrost regions, but icy-debris flows take a special place: they form in the composition of CGS and cryolithogenic systems, and outwardly similar objects emerge as a result. Icy-debris flows are the result of slow movement of debris material that includes ice. They differ in their origins, the nature of the fragments engaged in movement and type of ice inclusion and are part of genetically different systems, so there must be a thorough analysis of conditions related to them in order to prevent incorrect assessment. This is not always simple, owing to occasional external similarities between different objects: in terms of their permafrost genesis they are undoubtable as elements of cryolithogenic systems: debates occur when, defying the genetic hierarchy of geosystems, flows of permafrost origin are called rock glaciers, but use the German word "gletschers", thus equating them to glacial phenomena.

We highlight: gletscher is the German word for glacier. It began to be applied actively in the word combination stone gletscher in our literature to the glaciers saturated with moraine after the publishing of data by M.I. Iveronova [*1950*]: she habitually applied the term "gletscher" meaning glacier, which was a frequent practice at the time in Soviet science. The Terminological Committee of the RAS Glaciological Association later recommended not using the term "gletscher" in our literature, and the mentioned combination took the shape of "stony glacier". This was documented in the monograph of A.P. Gorbunov [*1988*], the lead specialist in this field. He later returned to the term "stony gletscher", considering it more convenient, but highlighted that its meaning is *stony mountain glacier* [*Gorbunov, 2006*]. Essentially, debris-saturated, or moraine-saturated, glaciers (this is more correct meaning-wise) are the object of particular cryogenic-glacial systems when the glacial process remains chief, but a lot of debris material comes down to the glacier from the slopes during active supplying of snow, and a slow-moving icy-debris body forms, the dynamics of which are determined by the initial snow component. The main developments on these were obtained in the Alps [*Barsch, 1996*], where they are typical and received the name *rock glacier* in English or *blockgletscher* in German (Fig. 4). However,

Fig. 4. Moraine-saturated glacier in the upper reaches of the Flaz River valley, Swiss Alps.
Photo by V.S. Sheinkman.

continuing to apply the term "stony gletscher", a number of authors [*Litkin and Galanin, 2016; D'yakova et al., 2017*] have set aside the genetic essence of glaciers it conveys and have carried over the name to a number of icy-debris objects of cryolithogenic geosystems. Even the term "corrom-gletscher" was proposed [*Romanovksiy, 1993*]. But a German word for glacier written in Russian letters (gletscher – "глетчер") is principally incorrect for defining the elements of cryolithogenic systems. This is also incorrect in terms of initially not frozen or thawed, then frozen moraines left by glaciers and adjacently lying talus, which the aforementioned authors also call "stony-gletschers". Especially because in English, which is the accepted language in science, the translation of the word "gletscher" is glacier, and thus signifies elements of cryolithogenic, not cryogenic-glacial, systems.

We note that buried ice that corresponds to the main body of the glacier is part of the glacier, and the dead-ice left behind during the glacier's retreat that has lost the ability to replenish and move is a different object – an icy-saturated moraine in transition to a diamicton. Heat easily makes its way through its coarse debris material with meltwater and air, and even under the conditions of continued permafrost, without the replenishing of the icy mass, the buried dead-ice body completely thaws during the first hundreds of years [*Sheinkman, 2011, 2016, 2017*]. Frozen talus is represented by different objects: lying on the slopes it can have weak movement, but calling them by the German name of the elementary geosystem "glacier" – "gletscher" is wrong. It is even more wrong to believe, ignoring the genetic differences, that because the buried dead-ice body is the result of warming climate, then all similar icy-debris bodies called stony gletschers relate to phenomena of the same type. As a result of organizing objects of genetically different systems that have different patterns of development into a single line, assessment of cryogenic conditions becomes distorted.

If researchers find it convenient to use the term "stony gletscher" somewhere, they should keep in mind that *stony mountain glacier* should be implied by it [*Gorbunov, 2006*], or, what is more exact, a *moraine-saturated glacier*. Recall that such glaciers are elements of CGS, the product of specific circumstances. With increased ablation and decreased supply they also become bodies of dead-ice, which then thaws. Azonal glaciers formed in places of accumulation of snow blown off of slopes also do not disrupt the principle of subordination of CGS objects [*Sheinkman, 2016*]. They lie lower than the climatic snow line, frequently among frozen talus, and compose, among others, moraine-saturated glaciers. Most importantly, the elements of geosystems to which they belong must be identified, strictly in compliance with their genetic affiliation.

Another example is carrying over of parameters of cryolithogenic geosystems onto entirely different, non-cryogenic formations, as in [*Alekseev, 2012*], where the traits of bulgunyakh development on alas plains are carried over onto an object known as the Patomskiy crater. This object is interesting because, amidst one of the slopes of the Patom Highland, in a mountain-taiga terrain that is homogenous for hundreds of kilometers, there is suddenly a large structure ~80 m in diameter and ~40 m in height composed of coarse material. The age of the object is ~500 years, there are many versions of its origin, but there are two main ones: the fall of a meteorite and the consequences of underground volcanic activity [*Moiseenko and Yazev, 2010*]. The Patom Highland is a middle mountain system approximately 300 × 300 km in size on the interfluve of the Lena, Vitim and Chara rivers, a cryohydrogeological massif where the top portions of the slopes are fissure-karst water absorption complexes, and the unloading of subsurface waters takes place at the base of slopes and in valleys with the development of small hydroaccolites and icings [*Litvin, 1989*]. Here precipitation is insignificant (~400 mm/year), and with an average annual air temperature of approximately −5 °C the permafrost temperature does not fall even below −2 °C, which prevents the development of low-temperature cryolithogenesis. Even with a maximally available temperature decrease in cryochrones freezing conditions of the highland will only approach those of modern-day Central Yakutia, where large bulgunyakhs are formed on the alas plains as a result of centuries-old freezing of sub-lake taliks. All known forms of this type are principally different from the Patomskiy crater in structure and nature of development and are significantly smaller. In any case, carrying over the characteristics of the systems over Central Yakutia to the native slopes of the Patom Highland because there is an object in the form of a cone composed of detrital material and considering it, as in [*Alekseev, 2012*], a gigantic bulgunyakh is incorrect.

As we see, the genetic features of elements of geosystems that unify phenomena yielded by cold are multifaceted. But thanks to their dissimilar and non-repeating features it is always possible to distinguish sets of them that will, despite terminological and other contradictions, serve as reliable evidence of their affiliation with particular geosystems and as a dependable instrument for assessing cryogenic conditions.

CONCLUSION

Vast biota and mineral resources are located within areas with cold climate; the need for the resources is felt increasingly strongly, and this requires heightened attention to manifestations of cold. They are studied by the science of Earth cryology, the development of which includes the broadening of the informational base of research, the perfection of methodological and multidisciplinary approaches and the organization of the conceptual-terminological apparatus. All of this provides for the creation of new geosystemic structures that enrich our knowledge about cold from the positions of cryodiversity and a systemic approach.

The specificity of various objects of the cryosphere is undoubtable, and it is extremely important to analyze phenomena yielded by cold as both objects of cryodiversity and in interactivity – as elements of cryogenic systems, overcoming, among other things, terminological contradictions justified by the diverse development of the branches of Earth cryology. It should be noted that it took several dozen years for new material to accumulate in order for the urgency of a general science analysis to become a reality once more after a long pause. It is arguable whether there is a purpose in raising such questions today, but the need to discuss them has ripened. This business is, undoubtedly, useful and justified, seeing as the science of the cold world has approached a milestone where extensive development can no longer always satisfy its arising needs.

We are in a new stage of forming conceptual knowledge about cold world phenomena, which is necessary for the organization of views of them in science. By identifying genetic features intrinsic only to them in the elements of cryogenic geosystems, entireties and subordinations of naturally combined phenomena yielded by cold can be distinguished in the margins of cryodiversity, and attributes of their affiliation with particular geosystems can be distinguished among them. In other words, a view from the perspective of cryodiversity and a systemic approach to objects yielded by cold, each of which has a set of dissimilar and non-repeated traits and carries a large volume of information, allows us to systemize the cryosphere's phenomena and create a reliable tool for the assessment of cryogenic conditions, including in ambiguous situations, especially in paleocryological debates. The authors hope that the questions of geosystemic structure and organization of terminology highlighted in this article, as well as sample analyses based on past cryogenic settings, will help solve current problems, including the resolution of collected contradictions.

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