Ice 0: the experimental proof of its existence – the result of combining approaches used in radiophysics, geology and geography

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Abstract. The experience of combining the efforts of researchers working at the interface of radiophysics, geology and geography is discussed. The effectiveness of such collaboration of researchers is shown by the example of the experimental proof of the existence of a new crystalline modification of ice, ice 0. This kind of ice is formed at the temperature below –23 °C out of supercooled water, and, together with ice Ih and ice Ic, may be formed at the temperatures and pressures corresponding to the surface layers of the Earth’s atmosphere. For this reason, this study is of great interest for understanding the natural processes taking place in the geospheres (atmosphere, cryosphere, biosphere, and hydrosphere).

1. Introduction

It is widely known that research at the interface of sciences allows the researchers to achieve important results in science. At the same time, the method of organizing complex research is not always clear, nor is it clear the specialists from which areas of knowledge should be invited for solving certain tasks.

In 1981, in the Chita Institute of Natural Resources, Siberian branch of the Academy of Sciences of the USSR (now the Institute of Natural Resources, Ecology and Cryology, SB RAS (INREC, SB RAS)), a laboratory of radio physical methods for solving the tasks of remote sensing in geology was established in Chita. One of the tasks faced by the laboratory workers was to investigate the microwave characteristics of natural ice, in order to contribute to the search for gas-generating deposits under lake bottoms [1]. The laboratory was established by the then director of the Institute Dr. F.P. Krendelev. However, as in every new business, the researchers were not completely sure of the success of the research to be conducted.

Yet, the experience of the subsequent years demonstrated the effectiveness of combining approaches and methods used in different disciplines, aimed at development of the geosciences (in this particular case, physics, geology and geography).

2. Discussion

The results obtained during four decades of working in INREC, SB RAS, allow the following conclusions to be made:
1. Geology and geography determine the vectors of research and set the tasks for physics applied in geosciences. This is related to the specifics of these sciences. Geography and geology investigate rather complex objects; therefore, they have elaborated their own methods and approaches based not only on knowledge but also on intuition and ‘qualitative’ characterization of the objects of study. Here experience and personal perception of the object by a specialist play an important role. At the same time, research in the area of physics (geophysics) allows substantiation of the conclusions made by geologists and geophysicists on the basis of fundamental knowledge. Geologists and geophysicists are inclined to ‘object-oriented thinking’ (characteristic of the early stage of development of classical physics) and often rely on tentative intuitive methods. In fact, geology and geophysics are parts of synergetic, i.e., the science investigating self-organization in nature. Synergetic operates rather complex non-linear processes and requires deep knowledge of not only geology but also physics, mathematics, chemistry, and biology.

2. I have noticed an important aspect of my colleagues’ work in the area of geology and geography: this is the absence of ‘fear’ of working at the interface of sciences, indicating that these specialists are characterized by the broad range of approaches to carrying out research. All the geospheres are inter-related; therefore, geologists and geographers have to find ties between them in studying different objects. For example, for a geologist biological processes are a natural geological force changing the geological environment. Therefore, a geologist conducting research should understand the main principles of the flow of biological processes in nature. Deep knowledge of physics, chemistry and biology by narrow specialists from different disciplines allows detection of these ties in a more effective way, when the efforts are united. However, the barriers on the way to breakthrough achievements often emerge when specialized approaches are applied. In my work of the past decades, I have often heard such statements, for example, from specialists in electrodynamics, as “your work is not related to remote sensing (electrodynamics) but refers to…”, etc., however, this statement sounds not like a reproach, rather, like a praise. On the other hand, geologists and geographers had little understanding of the way the methods of physics could be used in the geographic studies.

3. The main conclusion I have come to is that it is necessary to solve the problems of geology (and geography) on the basis of a common approach uniting physics with the standard methods used in geology and geography. Here the closeness (narrowness) of the physico-chemical approach, on the one hand, and of the geological-geographical thinking of a narrow specialist, on the other hand, should be overcome. That takes much time. In the organizational sense, it is optimal when specialists from different sciences unite to work at the common problems.

These conclusions are confirmed, in particular, by the fact that in our Geophysics of Cryogenesis Laboratory (the former Laboratory of Radiophysical Methods), we have been able to perform the research the results of which have been highly evaluated by the specialists from geology and geography laboratories. A good example is the experimental proof of the existence of a new crystalline modification of ice, ice 0 [2]. The original task of the search for oil and gas fields set by F.P. Krendelev necessitated the investigation of electrical physics of the mixture of water and gas. The subsequent integration project implemented with the Novosibirsk and Krasnoyarsk chemists to investigate nanoporous sorbents allowed us to understand the physics of water freezing in pores. Studying the existing literature on the theoretical research of crystalline ice enabled us to predict the existence of a new modification of ice formed only from supercooled water at the temperatures below –23 °C [3]. At the same time, many theoretically predicted modifications of ice were known, but it is not clear which of them could exist in the natural environment. As for ice 0, it could be formed at atmospheric pressure. However, it is rather difficult directly to identify it, for example, by the method of diffraction of neutrons. Therefore, since 2014, when paper [3] was published, no one has been able to solve the problem.

Success of the new solution was that we took notice of a study of the Novosibirsk scientists who investigated the issues of electric breakdown in high-voltage transformers. It turned out that at the interface of ferroelectrics and dielectrics, a layer of high electric conductivity emerges [4]. This
property allowed us to make an experiment on identifying formation of ice 0 in a porous dielectric medium [2], as it followed from the results [3] that this ice is a ferroelectric. Entirely new knowledge emerged of interaction of microwave radiation and thin conductive layers of nanoporous sorbents, as well as of the characteristic behavior of the electric structure of ferroelectrics. It was known about the ferroelectric that its domain structure demonstrates a hysteresis at cyclic changing of intensity of external parameters (electric field, temperature). These two features allowed us to make experiments on proving formation of ice 0 at freezing of supercooled metastable water. In the experiments, we used the assumption that in nanosized pores of silicate sorbents, the properties of water turn out to be close to those of volume water. That has been demonstrated previously in a number of studies, including ours. For porous water in the pores 4-6 nanometers in diameter, supercooling of water to −70 °C is possible.

The results of two experiments are shown in figures 1 – 3.

**Figure 1.** The plot of the average value of the noise voltage of wet SBA 15 at the output of the measuring instrument (U) vs temperature (T) of the medium during cooling and heating. Dashed lines are the values of U after taking into account the change of the cell impedance.

**Figure 2.** The results of measurements of the rate of change in the T of the cell with the medium (∂T/∂t) during its uniform heating. The numbers near plot indicate the phase transitions in wet SBA-15.
Figure 3. The plot of power reflection coefficient (R) of radiation at 12.4 GHz vs T from wetted Acros silica gel in the waveguide. The gravimetric water content – 3.5 %. Arrows indicate the direction of change of the temperature in the cooling–heating process.

In addition, we investigated the dielectric permittivity of wetted silicate sorbents at the frequencies of 100 Hz – 100 kHz, which revealed the extreme values of dielectric permittivity around –23 °C (figures 4, 5). From the results presented, there follows the existence of a temperature boundary of changes of electrophysical characteristics of ice near –23 °C. That was attributed to appearance of a new transition phase from liquid water to ice Ih and ice Ic, i.e. ice 0. Recently references of foreign researchers to the results of our works appeared [5].

Figure 4. The tangent of the angle of dielectric losses of wet SBA-15 (tgδ) vs T at 1 kHz. The gravimetric water content of the sample – 40%.
3. Conclusions
The proof of the existence of ice 0 having unique electrophysical characteristics opened up the previously unknown prospects for solving many problems of geography by using remote sensing. For example, formation of ice 0 in atmosphere is possible, which may be the cause of more intense attenuation and scattering of electromagnetic waves in the broad spectral band. It can be assumed that luminescence of noctilucent clouds appearing in mesosphere at the altitudes of 80 – 90 km is caused by condensation of ice 0 on dust particles. Their more frequent appearance over the recent decades may be related to the process of the Earth’s warming. Therefore, recording the appearance of noctilucent clouds is of interest for the monitoring of climatic processes. Special physico-chemical processes and phenomena may occur with ferroelectric ice participating in them. An example is formation of ozone holes, as well as manifestation of thunderstorm electricity. For frozen media, ice 0 should appear at formation of cryogenic structures and acceleration of cryochemical transformations. Some of the new issues related to ice 0 are discussed in [6].

This example is not the only one: similar achievements are known to have been made in the other laboratories of the Siberian branch of the Russian Academy of Sciences. The main conclusion regarding the results of the work of combining the scientific methods, approaches and assumptions of different scientific disciplines is the high effectiveness of such efforts in the progress of geosciences.

References
[1] Bordonskii G S, Polyakov S V and Krendelev F P 1985 *Russian Geology and Geophysics* **26** 66–73
[2] Bordonskiy G S and Orlov A O 2017 *JETP Lett.* **105** 492–6
[3] Russo J, Romano F and Tanaka Y 2014 *Nature Materials* **13** 733–9
[4] Korobeynikov S M, Melekhov A V, Soloveitchik Yu G, Royak M E, Agoris D P and Pyrgioti E 2005 *J. Phys. D: Appl. Phys.* **38** 915–21
[5] Leoni F and Russo 2021 *Phys. Rev. X* **11** 031006
[6] Bordonskiy G S, Krylov S D and Gurulev A A 2020 *Ice and Snow* **60** 263–73.