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On the Methodology of Subglacial Oceans *

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Abstract. Throughout all periods of development, the history of mankind has been closely intertwined with the sea. Craving for perception of the unknown has always been favored for humans. The interrelations between people and water element were actively considered by the representatives of natural, exact and engineering sciences. Humanitarian thought can also make a contribution to the study of the oceans. The authors propose substantiation for the formation of the methodology of subglacial oceans. The methodology refers to the theory of thought and action. Modern methodology is capable of constructing the ways of thinking that solve new issues and problems. Openness to criticism of methodological thinking is its strong and promising aspect. The study of the exploration techniques of the "second space", starting with the first steps and up to the modern attempt to create an underwater prototype of the International Space Station, leads the authors to the conclusion about the possible equivalence of space and Arctic technologies. Exploration of the ice cosmic worlds of Pluto, Jupiter and Saturn may precede the study of the Arctic region. The Arctic has the potential to become a testing site for future space missions. The sterility of space technologies can, on the other hand, provide the development of the green economy in the Arctic.
Keywords: *ocean, Arctic, subglacial oceans, space, methodology for exploring the oceans.*

Thor Heyerdahl wrote: "Man hoisted sail before he saddled a horse. He poled and paddled along rivers and navigated the open seas before he traveled on wheel along a road. Watercraft were the first of all vehicles. By hoisting sail or merely traveling with the current, early man was able to settle the islands. Territories that could be reached overland only by generations of gradual transmigration for those who had to confront obstacles like swamps and lifeless tundra, naked mountains and impenetrable jungles, glaciers and deserts could be reached in weeks by casual drift or by navigation. Watercraft were man's first major tool for his conquest of the world." [1, T. Heyerdahl, p. 3]. Ocean developed in man a craving for wandering and knowledge of the unknown. It has been established long ago that in order to understand the nature of the Earth and neighboring planets, it is necessary to consider all the phenomena of solar system as a whole. Studying the Earth, man in a certain way studies the history of the entire Universe. Human mind has never reconciled and will never reconcile with the existence of the unknown. To explore the unknown and explain the incomprehensible, a person does not stop at any difficulties.

Humanitarian thought can make a significant contribution to the process of oceans exploration. Within the framework of the article, we will start from descriptive works [2, Scholtz G. et al.[1]] and turn to methodological aspects of the issue.

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To date, about 580 inhabitants of our planet have flown into space. A total of 13 people have visited the moon. Only three people have conquered the maximum ocean depth in the Mariana Trench. But no one has seen the real North Pole until now: the ocean bed under a solid ice cover. No one dared to descend to the bottom of the top of the world to a depth of 4300 meters under an ice dome of 2.5 meters. This was done only by a Russian expedition led by the outstanding polar explorer Artur Nikolaevich Chilingarov. The landing of a deep-sea vehicle on the bottom of the Arctic Ocean near the North Pole can be classified as a geographical discovery. No one in the entire history of mankind has come into direct contact with open space, which could not but affect the mental state of cosmonaut A.N. Leonov. None of the people have ever been at such a depth, and even under the ice of the North Pole. All this was taken into account by the organizer of the expedition. "It was a victory of human mind, will, courage, daring, aspirations to comprehend the unknown, which had not been conquered before. It was a leap of trust" [3, Sagalevich A.M., p. 266]. Into the "second space".

The exploration of the ocean as a "second space" is increasingly attracting the attention of the international scientific community. Fabien Cousteau, the grandson of legendary ocean explorer Jacques Cousteau, wants to build the equivalent of the International Space Station (ISS), but on the ocean floor deep below the surface, as CNN reports. "Ocean exploration is 1000 times more important than space exploration for our survival, for our trajectory into the future," Cousteau told CNN. "It's our life support system. It is the very reason why we exist in the first place." Space exploration gets vastly more funding than its oceanic counterpart, according to CNN, despite the fact that humans have only explored about five percent of Earth's oceans and mapped only 20 percent [2].

Claude Jean Riffaud writes that a parallel can be drawn between work underwater and in space. "They are related to the life support of a person in unusual conditions. The oceanaut, like the astronaut, is isolated in his capsule, he is threatened by lots of dangers. The first one is separated from the usual terrestrial world by the endless space, the second — by a gigantic layer of water, and the huge hydrostatic pressure is no less dangerous than the vacuum. It takes about the same time for return from the Moon to the Earth and for transition from pressure at a depth of 250 meters to normal earth pressure." But the history of ocean exploration has its own peculiarities. "A person has long had the opportunity to explore the underwater world, with certain restrictions" [4, Riffaud, p. 110–111].

For a long time, space exploration seemed to be a matter of manned astronautics. Humans can inhabit near-Earth space in orbitals, the Moon, maybe even Mars. But it's a divergence of humanity. Distant worlds are only open to robots. So is the ocean. Humans can explore the shelf, but

[1] Zaucha J., Gee K. Maritime Spatial Planning: Past, Present, Future. Springer Nature, 2019. 496 p. https://doi.org/10.1007/978-3-319-98696-8_2 (accessed 02 September 2020).

[2] Tangermann V. Check out This Amazing Design for an Underwater «Space Station». Ocean exploration is 1,000 times more important than space exploration». *Futurism*. URL: https://futurism.com/check-out-this-amazing-design-for-an-underwater-space-station (accessed 02 September 2020).

great depths are a task for automata. The pioneering heroes are being replaced by robots. Thus, the Russian autonomous vehicle “Vityaz” made an expedition to measure the real depth of the Mariana Trench. As a result, its sensors recorded a depth of 10,028 meters. The duration of the underwater expedition, during which the “Vityaz” carried out mapping, photo and video filming, was about three hours. The apparatus functioned in a completely autonomous mode, the specialists just observed the progress of the operation. Full autonomous operation distinguishes the “Vityaz” apparatus from Japanese and American underwater devices that are engaged in scientific research in the area [3].

What is so interesting about the Arctic in this respect? What could be a subglacial oceans methodology? The Arctic allows you to touch the mystery of life origin on other ice worlds.

A recent analysis of images of the automatic interplanetary probe New Horizons, taken by scientists at the University of California, showed that immediately after formation, Pluto could be so warm that an ocean of liquid water existed on its surface. The giant Sputnik Planitia glacier is located exactly in the *anti-charon* zone. It is placed in area that is opposite to the section of Pluto's surface where Charon (Pluto's satellite), tied by tidal forces, always stands directly overhead. This could happen only if Pluto's inner rocky core and its outer ice crust are not connected to each other by frictional force due to the existence of an ocean with liquid water under the ice crust. Could this ocean be inhabited? According to astrobiologists, liquid water is a fundamentally necessary factor for the existence of life, along with the molecules of organic substances and the flow of energy. All these conditions may be available on Pluto and other worlds with internal oceans, such as Europa and Enceladus [5, Stern A., p. 355–357]. Half the mass of Charon's inner core is water ice. It is known that during the satellite formation, its core was hot, making water ice liquid. Ice freezing caused internal expansions, resulting in a huge tectonic belt. The northern and southern hemispheres of Charon are separated by a huge complex of valleys and rocks, which stretches for more than 1,500 km at an acute angle from the equator from southwest to northeast.

Pluto is not the first ocean world. Astronomers hope to explore giant pools of liquid water on the moons of Saturn and Jupiter. Perhaps the most famous of these is Enceladus, one of Saturn's moons. In 2004, the interplanetary station “Cassini” discovered huge water geysers up to 250 kilometers high above its south pole, which became important evidence of existence of a global ocean under the solid surface. According to estimates, its depth reaches 45 kilometers, which is four times deeper than the Mariana Trench. The thickness of the ice layer over the ocean is from 18 to 22 kilometers (although ice at the south pole is believed to be much thinner: from 2 to 5 kilometers).

Another famous example of the ocean world is Europa, a small moon of Jupiter with a radius four times smaller than the Earth's (by the way, this is the smallest of the planet's moons dis-

[3] Noveyshiy rossiyskiy glubokovodnyy apparat «Vityaz» opustilsya na dno Marianskoy vpadiny [The newest Russian deep-sea vehicle "Vityaz" sank to the bottom of the Mariana Trench]. URL: https://www.militarynews.ru/story.asp?rid=1&nid=531602&lang=RU (accessed 02 September 2020).

covered by Galileo). Scientists suggest that a salty ocean is hidden under its icy surface, the depth of which should be one tenth of the entire radius of a celestial body. The volume of water in the "European Ocean" is two to three times greater than in the World Ocean on Earth, and it is preserved in liquid form due to tidal forces. This fairly common mechanism for heating celestial bodies without using the energy of the Sun or internal radioactivity works this way: when a moon orbiting Jupiter comes close to a gas giant, the gravity of the latter flattens it slightly, and it stretches along the direction of the planet. Then, when the celestial body moves away from Jupiter, Europa again takes on a spherical shape. Such regular deformations promote mixing and heating of the subsoil, which prevents the subglacial ocean from freezing, and also creates partially melted "pockets" throughout the entire outer shell of Europe [4].

Triton was born in the Kuiper Belt, a ring of ice rocks orbiting the Sun outside the planets. Early in their lives, Neptune and Uranus engaged in an intricate dance that transported them and the Kuiper belt to their present locations. This cosmic accident also allowed Neptune to capture at least one Kuiper belt object, Triton, as the moon. The surface of Triton probably felt the first bursts of activity during this violent takeover. Tidal heating caused by energy dissipation during this takeover and slow circulation of its orbit probably caused geological activity at the surface. The ice may have moved or melted, and its internal structure may have been slightly affected. But this event alone, happened billions of years ago, is not enough to preserve the freshness of Triton's surface. Something else must be heating its interior today to create a liquid ocean. On Europa, the variable gravity tug of Jupiter and its moons may help preserve the ocean, but Triton is Neptune's only large moon. Instead, Triton's orbital tilt could lead to formation of a liquid ocean. Although the Moon is always turned with one side to its planet, its orbital retrograde motion occurs above and below the equator of Neptune, which allows its poles to experience the changing seasons, and the giant planet's gravitational action effects Triton's inner surface [5].

Astronomers analyzed the data obtained by the Dawn spacecraft between 2015 and 2018. The results suggest that there is a salty ocean beneath the surface of Ceres. It is also possible that the celestial body was geologically active not so long ago. The Dawn spacecraft orbited Ceres, a dwarf planet and the largest known object in the asteroid belt, from 2015 to 2018 until it ran out of fuel. In the final phase of Dawn's operation, it entered orbit just 35 km above the surface of Ceres. Its goal was to analyze the structure of the Occator crater, since scientists noticed salt deposits on its surface, which were thought to get there from the subsurface ocean. In the first

[4] Ulasovich K. Na Plutone, okazyvaetsya, est' drevniy okean vody. Uzhasno interesno, chto tam proiskhodit, – no dlya nachala pridetsya izuchit' okeany Entselada i Evropy [It turns out that Pluto has an ancient ocean of water. Terribly interesting what is happening there — but first you have to explore the oceans of Enceladus and Europa]. URL: https://meduza.io/feature/2020/06/24/na-plutone-okazyvaetsya-est-drevniy-okean-vody-uzhasno-interesno-chto-tam-proishodit-no-dlya-nachala-pridetsya-izuchit-okeany-entselada-i-evropy?utm_source=twitter&utm_medium=main (accessed 20 September 2020).

[5] Redd N. T. What lies beneath Triton's ice. *Astronomy*. URL: https://astronomy.com/magazine/2019/08/what-lies-beneath-tritons-ice?utm_source=asytwitter&utm_medium=social&utm_campaign=asytwitter (accessed 20 September 2020).

phase of the work, astronomers analyzed high-resolution gravity data and images from the spacecraft and discovered that there is a huge reservoir of salt water deep under the Occator crater. Researchers suggest that the impact of a celestial body that created the Occator crater could have caused the rise of salt water to its surface. Then scientists investigated the composition of the hard crust of Ceres. They hypothesized that the dwarf planet experienced a period of cryovolcanic activity that began about nine million years ago and continued until recently. In a separate work, astronomers showed that the hills in the Occator crater could have formed by the freezing of lava flows after the impact of celestial bodies on the surface of Ceres. It means that cryogenic processes are possible not only on Earth and Mars, but also on Ceres. The age of Occator is estimated at about 20 million years, while the age of the light deposits — several million years. Therefore, scientists were inclined to the second hypothesis, according to which water and soda are contained at a greater depth in the form of a saturated liquid solution and rise to the surface due to cryovolcanic activity. The detected gravity anomalies suggest that there is indeed a reservoir of fluid under the crater [6].

The gas giant Jupiter was believed to be responsible for the tidal heating of the liquid interior of its moons. In a new study, scientists at the University of Arizona believe that the satellites are able to warm themselves up due to the mutual gravitational influence that exists between them. According to the researchers' new model, Jupiter's influence cannot create tides at the right frequency to resonate with moons, because their oceans are considered too deep. When researchers added the gravitational influence of other moons, they noticed tidal forces approaching the natural frequencies of the satellites. When the tides created by other objects in the Jupiter satellite system match the natural resonance frequency of each moon, then the moon begins to heat more than due to the tides raised by Jupiter alone, and in the most extreme cases it can cause ice melting. According to experts, for moons to experience tidal resonance, their oceans must be tens to hundreds of kilometers – at most a few hundred miles – thick, which is in range of scientists' current estimates. Researchers believe that protecting sub-ice oceans from freezing requires a delicate balance between internal heating and heat loss, and yet there is some evidence that Europa, Ganymede, Callisto, and other moons could be ocean worlds. For example, volcanic activity is observed on the moon Io, which, according to scientists, is one of the consequences of tidal heating. “These tidal resonances were known before this work, but only known for tides due to Jupiter, which can only create this resonance effect if the ocean is really thin (less than 300 meters or under 1,000 feet), which is unlikely,” — says the study’s lead author Hamish Hay in one of his interviews [7].

[6] Pod poverkhnost'yu Tserery nakhoditsya okean solenoy vody [Beneath the surface of Ceres is an ocean of salt water]. URL: https://indicator.ru/astronomy/pod-poverkhnostyu-cerery-okean-solenoi-vody-10-08-2020.htm (accessed 27 September 2020).

[7] Mace M. Jupiter's Moons Could be Warming Each Other. The gravitational push and pull by Jupiter's moons could account for more warming than the gas giant Jupiter alone. *News of the University of Arizona*. URL: https://news.arizona.edu/story/jupiters-moons-could-be-warming-each-other (accessed 27 September 2020).

When the tides created by other objects in the Jupiter satellite system match the natural resonance frequency of each moon, then the moon begins to heat more than due to the tides raised by Jupiter alone, and in the most extreme cases it can cause ice melting. According to experts, for moons to experience tidal resonance, their oceans must be tens to hundreds of kilometers – at most a few hundred miles – thick, which is in range of scientists' current estimates. Nevertheless, there are some reservations to the researchers' conclusions. Their model assumes that tidal resonances never get too extreme, Hay said. He and his team want to return to this variable in the model and see what happens when they lift that constraint. Hay is hoping that future studies will be able to infer the true depth of the oceans within these moons. Warm deep oceans are the main hope of those seeking extraterrestrial life in the solar system. None of the ice worlds have been properly studied, but astronomers already have many specific plans for research missions [8].

The Arctic can become a testing ground for such missions.

For example, the American space agency NASA is planning a mission to Jupiter's satellite Europe in order to search for life in the oceanic worlds. Engineers at NASA Jet Propulsion Laboratory in Pasadena have created the Buoyant Rover for Under-Ice Exploration (BRUIE), which is currently being tested in Antarctica. A three-foot (1 meter) floating all-terrain vehicle equipped with two wheels for rolling under the ice can take pictures and collect data in an important area where water and ice meet [9].

From the above, **the methodology of subglacial oceans** is the following: Based on the universality of the scientific method, what is suitable for space can be applied to study our planet. We can talk about the equivalence of space and Arctic technologies. By studying Arctic Ocean, we are exploring all possible subglacial oceans. For example, one of the activities of the robotics departments can be reoriented towards the development of robots for autonomous exploration of the Arctic. Subsequently, they can be used in outer space in the study of sub-ice oceans of other celestial bodies.

This research touches upon the essence and origin of life, possibility of its occurrence in a closed hydrospace. A group of researchers from the Free University of Berlin have found data indicating the existence of life in the subglacial ocean of Enceladus. Traces of organic compounds in plumes that burst from the moon surface may be the building blocks of amino acids, the precursors of terrestrial life forms. It is not known if amino acids are needed to build alien lifeform, but finding the molecules that form amino acids is an important piece of the puzzle.

The plumes are ejected from the surface of Enceladus after mixing with water from the moon's giant sub-ice ocean, and then the material is ejected in the form of water vapor and ice

[8] Hay Hamish C.F.C., Trinh A., Matsuyama I. Powering the Galilean Satellites with Moon-Moon Tides. *Geophysical Research Letters*. 2020. Volume 47. Iss. 15. DOI: https://doi.org/10.1029/2020GL088317. URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020GL088317 (accessed 27 September 2020).

[9] Samuelson A. Aquatic Rover Goes for a Drive Under the Ice. *Jet Propulsion Laboratory California Institute of Technology*. URL: https://www.jpl.nasa.gov/news/news.php?feature=7543 (accessed 27 September 2020).

grains. NASA's Cassini spacecraft was able to analyze it using an onboard mass spectrometer. The news appeared after another group of researchers suggested in 2018 that complex organic molecules float on the surface of Enceladus's vast subsurface ocean. In June, a team from the Washington University discovered that the ocean is nutrient-rich and livable.

In the Earth's ocean, plankton is the basis of life: where phytoplankton (photosynthesizing unicellular algae) appears in the mass, life begins. It releases oxygen, which the oceans produce more than all forests in the world. In the northern seas, the appearance of phytoplankton is tied to the appearance of the sun after a long polar night. Cold seas are more saturated with oxygen than warm ones (the solubility of gases in water increases with decreasing temperature). The presence of a sufficient amount of oxygen and food leads to explosive outbreaks of abundance, because the plankton biomass in the northern seas can be unimaginably huge [6, Semenov A., p. 15].

This is the difference between the terrestrial arctic seas from the subglacial oceans on other celestial bodies. It is obvious that anoxic life is possible there, as in the deep oases of the Earth's ocean. Such oases are usually located along rift ridges.

Space technology is generally sterile. Researchers are seeking sterility in order not to pollute other planets. This means that space technologies are environmentally friendly. This is very important for such a sensitive region as the Arctic.

Many of the robotic gliders and floating sensor stations currently monitoring the world's oceans are effectively treated as disposable devices. "This is because the research community has a limited number of both ships and funding to retrieve drones after they've accomplished their mission of beaming data back home. That's not only a waste of money, but may also contribute to a growing assortment of abandoned lithium-ion batteries polluting the ocean with their leaking toxic materials," said Yi Chao, president and CEO of the Seatrec startup. Seatrec's energy-harvesting system works by taking advantage of how certain substances transition from solid-to-liquid phase and liquid-to-gas phase when they heat up. The company's technology uses pressure changes resulting from such phase changes to generate electricity. The startup is working to adapt its system to work with autonomous underwater gliders. To make the phase changes happen, Seatrec's solution taps the temperature differences between warmer water at the ocean surface and colder water at the ocean depths. "Even a relatively simple robotic probe can generate additional electricity by changing its buoyancy to either float at the surface or sink down into the colder depths." [10] This fits well with the green economy and the use of renewable energy sources.

Among all the possible applications, startup founder Yi Chao is particularly excited about the prospect of Seatrec's renewable power technology enabling underwater drones and floaters to collect oceanographic data for much longer periods of time. He spent most of two decades working at NASA Jet Propulsion Laboratory (JPL) in Pasadena, California, where he helped develop a satellite designed to monitor the Earth's oceans. He and the JPL engineering team that devel-

[10] Ibid.

oped Seatrec's core technology believe that swarms of underwater drones can provide a continuous monitoring network to truly begin understanding the oceans in depth [11].

The unity of world science is manifested in the project for the study of subglacial oceans. The efforts of all countries within the Arctic Circle can be united. Finally, a kind of *dream project* arises. Such a project does not bring immediate benefits, but its development significantly promotes science and technology, attracts young, promising personnel who are in love with the Arctic, and engages young people to the field of scientific research. It develops a cosmic worldview, allows considering the Universe as a whole, because the Earth is one of the many worlds covered by the ocean.

In conclusion, we must recall why it is important to refer to methodology. It is known that the construction of methods dates back to the late 19th – early 20th centuries [12]. In conclusion, we must recall why it is important to refer to methodology. It is known that the construction of methods dates back to the late 19th – early 20th centuries. V.M. Rozin identifies a number of features characteristic of this trend. “Generally, methods are understood as methods of correct thinking, and the criteria for correctness can be different (consistency, creation of conditions for further development of thinking, the possibility of building new knowledge). Methods are created by methodologists, but based on already emerging patterns of thinking, which are described and analyzed from a certain angle of view. Methods are addressed to certain audiences (in particular, scientists), who impose certain requirements on the content and form of these methods. We get *a specific methodology of research* [13]. According to G.P. Shchedrovitsky, *methodology* is the doctrine of thinking and action. From thinking according to the schemes of two or many knowledge, the task of *configuring knowledge* follows quite naturally. “Collective forms of methodological thinking contribute to the fact that methodological thought is constructed in such a way as to prepare the conditions for the next new thought. Modern methodology sees its purpose in restructuring and reforming unsatisfactory forms and ways of thinking and in building ways of thinking that allow solving fundamentally new problems and tasks. Methodological thinking is open to criticism, it waits for it, exposes its thoughts for discussion to interested subjects. The third main characteristic is the reliance in solving methodological problems and tasks on modern intellectual technologies and the scientific study of thinking” [7, V.M. Rozin, p. 98].

From the above, our proposal for the methodology of subglacial oceans is following:

1. Based on the universality of the scientific method, what is suitable for space can be applied to study our planet. We can talk about the equivalence of space and Arctic technologies. By studying Arctic Ocean, we are exploring all possible subglacial oceans.

[11] Ibid.
[12] Rozin V.M. Rekonstruktsiya «Logiko-filosofskogo traktata» L. Vitgenshteyna [Reconstruction of the "Logical-Philosophical Treatise" by L. Wittgenstein]. URL: http://www.e-notabene.ru/fr/article_571.html#4 (accessed 27 September 2020).
[13] Ibid.

2. We propose to reorient some of the functionality of the robotics departments to develop robots for autonomous exploration of the Arctic. Subsequently, they can be used in outer space in the study of both subglacial oceans and other celestial bodies.
3. This research touches upon the essence and origin of life, possibility of its occurrence in a closed hydrospace. This concerns the kinship of all living creatures in space.
4. Space technologies are usually sterile. Researchers are seeking sterility in order not to pollute other planets. This means that space technologies are environmentally friendly. This is very important for such a sensitive region as the Arctic.
5. This issue reveals the unity of world science. The efforts of all countries within the Arctic Circle can be united.
6. A kind of dream project arises. Such a project does not bring immediate benefits, but its development significantly promotes science and technology, attracts young, promising personnel who are in love with the Arctic, and engages young people to the field of scientific research. It develops a cosmic worldview, allows considering the Universe as a whole, because the Earth is one of the many worlds covered by the ocean.

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