Antarctic Subglacial Lake Ecosystem Research

Edward Whitesel

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Life on earth is one of its most distinguishing aspects. Such is its prevalence that much of the atmosphere is influenced by it and the surface coated by it. From the empty ocean and vast deserts there is always some kind of life existing there. Throughout earth history life has been present three quarters of it and growing. For something so pervasive to earth and something that we are, it is important to understand it to the best of our abilities. This means oddities and quarks, especially related to its ability to adapt and survive. This is where the Antarctic becomes pivotal. The Antarctic is considered one of the most inhospitable places on earth being in a perpetual frost, life struggles to survive there. Despite this struggle there is still life, in the water and on the coast seals penguins and fish do survive and even thrive in this inhospitable place. One thing they have in common though is their connection to more hospitable places. While it is cold they still have light for photosynthesis or the waste from those that do, the animals that exist here can theoretically swim to places beyond. What if this weren't the case. What if there existed places where life can exist yet entirely separate from the rest of the world. In science fiction and fantasy this has been imagined as fantastical islands or mythical caves filled with creatures from the far past such as dinosaurs long lost to the rest of the world. While dinosaurs do not exist in such a case, at least to our knowledge, there are places isolated to this extreme degree. Antarctica specifically contains many of these environments. Due to extreme weather many places such as the dry valleys are functionally isolated as few foreign lifeforms can access it. There is a place that is even more isolated however. One that not only is isolated in a functional sense but a literal, sealed in a tomb of ice and rock. These are the subglacial lakes that dot the Antarctic. These subglacial lakes can provide insightful information not only on the life in the antarctica and biology of extremophiles but also the implication for life in other inhospitable places.

The biology present in subglacial lakes is strongly formed by the formation of these lakes. Their formation indicates the methods that can be used to research them as well as the characteristics of the environment. Antarctica subglacial lakes form several factors with two common methods through how they form. One of these is the pressure existing under the ice, this causes the freezing point of the water to change to a point that the temperature is reachable via natural forces. This specific natural force is the geothermal vents which through the ice being an insulator allows for the ice to melt into a pool forming a stable lake underneath the glacier [1]. The second method is through being trapped via glaciers forming over a pre-existing body of water. This method allows for the possibility of organisms getting trapped in the lake at the time of entombment. This means that the ancient organisms that existed at the time could still have their descendents alive in these lakes unlike the rest of the world where they have gone extinct. These don't freeze over for the same reason as the first. These subglacial lakes can have rivers connecting them where high pressure streams flow between them and even some connected to the outside ocean surrounding the antarctic. There are also some that are entirely isolated from even other subglacial lakes. These lakes can affect the glaciers they lie under. Through their flow it has been hypothesized that the movement of glaciers is influenced [2]. accretion layers are another part of a subglacial lake forming on the glacier. These glacial layers consist of lake water freezing onto the glacier. These accretion layers glide over the lake carrying information on the contents of the lake from the time they froze, providing a timeline that can be studied of the lake environment. So far in the Antarctic there have been approximately 600 subglacial lakes found [2]. The largest of these is Lake Vostok, having a total volume of 5400 cubic kilometers. Other lakes include lake Concordia and lake Aurora all of which clustered in the eastern region of

Antarctica. Many of these lakes have had bases recently established, some notable ones being lake Vostok and lake Aurora.

Finding subglacial lakes is not trivial. Unlike regular formations such as mountains or valleys. The naked eye cannot observe them. Much like cave systems they exist too far underground to have any noticeable impact on the more observable surface. Because of this they can only be observed via means that penetrate the surface. This is primarily done to Radio Echo Sounding(RES) [1]. RES utilizes high frequency radio waves to penetrate the ice bouncing back indicating the topology underneath the ice. When done over bodies of water the RES data indicates a uniquely flat area unlike the surrounding bedrock [1]. This allows for researchers to pinpoint where and how deep the body of water is. They can determine depth via the time for an echo to be heard. This technology was how the first subglacial lakes were found in the 1960s through initial scanning of the underlying surface of the antarctic. When researchers were attempting to map the underlying surface of Antarctica using RES they noted the unusual flat spots, realizing they were subglacial lakes[1]. The process of actually producing many aspects of this research is not simple. The standard practice is to utilize airplanes carrying the RES equipment in order to quickly change position while constantly reading and sending signals. The difficulty of this is the challenge of flying a plane in Antarctic weather and terrain. Due to weather course deviations becoming necessary, the challenge of this being any course deviation has to be meticulously noted for the sake of the RES data [5]. As Antarctica weather, while predictable, isn't done for the whole Antarctic. Because of this, revisions become necessary in order to reduce flight risks [5]. The other difficulty arises due to the terrain being scanned, while flat even terrain is trivial to scan, the more treacherous terrain was not nearly as simple. When icey terrain became more jagged and treacherous noise from the surface became too great necessitating a lower ground clearance of about 500 meters[5]. This increases risk as flying this low risks collision with terrain. For normal terrain 1000 meters would suffice provided good data while benefiting from increased altitude [5].

Due to their location and isolation, access to these lakes is inherently difficult. They exist hundreds of meters below ice along with being in a location inherently uninhabitable. This has already made them difficult to research, made all the more by them only being discovered in the 1960s[1]. The final Challenge about researching these geological phenomena is the desire to preserve what they are. From what research has indicated these lakes may contain very vibrant, ancient, but also delicate microorganisms that risk being destroyed by contamination. This means that any sampling must be done with utmost care not to chemically or biologically contaminate the lake. This has meant most research has not invested in collecting lake samples instead relying on less intrusive methods for analysis of more geologic features. Despite these challenges there is still great interest in obtaining a water sample of these lakes, and despite the difficulties and challenges it is not impossible. The first hurdle to overcome is reaching the lake. This involves drilling down to just above the lake surface, a process that is generally slow and tedious. Compounding this with the difficulty of maintaining a biologically clean environment the task is made more difficult. Initial drilling can be made simple by using traditional means such as thermal, it is only imperative that the final access point to the lake be kept sealed and away from any contaminants. Thermal drilling utilizes a constant heat to melt the ice allowing for a hole to be formed. Due to the low temperatures of the Antarctic one challenge with this method is freezing of the components. Thermal drills tend to use water because of this the water needs to contain some form of antifreeze [6]. The difficulty arises when these antifreezes become pollutants to be avoided in the sampling of the lake [4]. Because of this otherwise optimal method is discouraged due to pollutants. This is why mechanical is often preferred in current research, despite this there tend to still be pollutants present, the benefit being that they can be sealed away unlike thermal drilling which directly sprays a solution containing the pollutant. This method involves taking chips of the ice and storing them in order to be deposited at some future point [7]. The difficulty of this drilling method is the rotary motion which needs to be stabilized. Another issue is the varied properties of ice at different locations. As ice changes properties the effectiveness of drilling can change to degrees that it affects the efficiency and stability of the operation. Once an opening is formed drilling can cease. The pressure from the lake causes the lake water to fill the bore hole. It is important that this water does not contact the drilling device due to the possibility of polluting the lake with antifreeze chemicals. The water filling the borehole will eventually freeze where it can be then taken as a core sample to be analyzed. Possible methods to sample the lake bed for geological analysis have been proposed involving opening a wider hole to insert a sampling device. A difficulty of the sampling device is the inability to have any rotary motion as the lack of counter force to drill the bedrock. Because of this the method used is to drop the sampling device several meters above the location allowing gravity to create the necessary kinetic force to penetrate the rock [4]. Because of this method getting a larger sample involves repeating this dropping process multiple times, this means that getting a large sample from a specific point is difficult [4]. This process has yet to be done and serves mainly for geological research yet due to

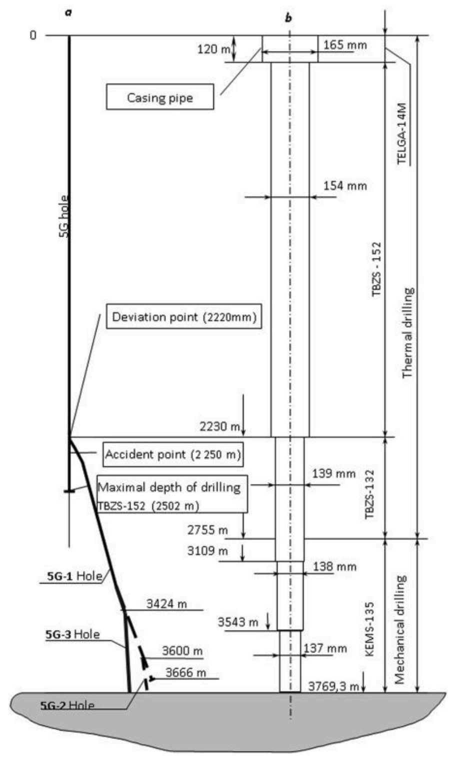
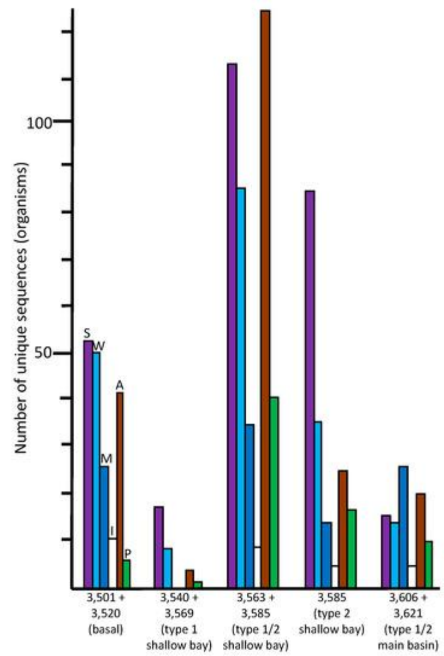


diagram of 5G borehole at lake Vostok[4] the need for thermal vent ecosystem analysis may prove useful. There is however interest in the lake bed ecosystem as this may contain a different biological makeup. Instead current methods involve drilling just up to the lake letting water flow into the bore hole where it can freeze and be collected[7]. This allows for analysis of the later thawed core of frozen lake water allowing for a method to collect lake water without contamination. Because the upper portion to the lake freezes to the glacier above the lake this creates a layer of lake water frozen in time to drift with the glacier. This can be sampled through traditional core samples, albeit with regards to sterilization, and be examined. This gives insight into the lifeforms in the lake. Along with this the glacial movement allows for pictures of the lake ecosystem to be stored and give researchers an understanding of the changes of the ecosystem[8].

Through the process of sample extraction of lake water discussed the process was carried out on the largest subglacial lake in Antarctica, lake Vostok. From these samples collected from the subglacial lake Vostok it was found that there were unique traces of life [3]. This was determined through a wide variety of methods in order to extract and enhance the traces of species present in the lake. Through several complex chemical and biological processes the present DNA and RNA is enhanced and examined to determine the present organism in the environment[3]. These DNA and RNA samples are in theory the remains of organisms and their traces. This involves utilizing the RNA to synthesize further cDNA abbreviation of copy DNA [3]. After this a series of steps is done in order to further enhance the DNA so that the results can be made as clear as possible. Some of these steps include several enhancements of the samples via creating copies through several complex methods ultimately ending up with much more clarity than the initial sample . From this sample the contents can be analyzed.

From the process of examining the lake contents researchers have found a variety of interesting results. A study done for accretion laye of ice consisting of frozen subglacial lake water examined the biological contents of the sampled cores. Sampling at various depths the cores were treated and then melted at room temperature in a sterile environment. Upon examining the samples they found the most biodiversity among ice samples of accretion ice of the lake[3]. Some of the specific traces they found that could not be explained as contamination indicated the presence of complex multicellular organisms such as arthropods, mollusks and crustaceans in the form of bacterias and DNA sequences associated with them[3]. These findings indicate that the lake may contain a complex and diverse ecosystem. Another study of the actual lake water indicated that there are living organisms present. In the study they found, after disregarding contaminants found they discovered an unidentified, unclassified, and unknown bacterial phylotype designated w123-10 [9]. This indicates the possibility of microbial life surviving in the harsh environment. It also indicates there may exist organisms present that have no equivalent in our own understanding of lifeforms. The researchers also indicate the possibility of far greater biodiversity among the lake bed, where thermal vents create a far more livable environment compared to the over-cooled upper portion close to the glacier [9]. A sample from this region of the lake could also provide a much more clear picture of the lake ecosystem. Those lifeforms that make their way closest to the glacier are most likely the outliers, the extreme species that live on



unique sequences in ice core samples matching with NCBI databse [3].

the fringes. While the more accurate representation of the ecosystem exists further below in the lake closer to where the sources of possible nutrition and warmth are.

The findings and research done on these ecosystems have implications for biology in these lakes and beyond. For biological research the research done on these lakes provides a much greater understanding of the nature of extremophile life forms. It demonstrates that lifeforms can exist in environments entirely devoid of life and outside contact as well as existing in extreme temperature environments. Life from these environments can't teach researchers new ways in which it can exist. Evolution tends to have the ability to adapt in ways that people can never predict. Because of this, understanding how life adapts to these harsh environments is important for understanding the upper limits of where life can exist. The implication of life being able to exist on earth's harshest environments provides the idea that it may exist elsewhere in the solar system. The environments of a subglacial lake and another planet are surprisingly similar. Places deep inside Mars, or moons of Jupiter such as Europa are strikingly similar to subglacial lakes[10]. This may indicate that it is possible for life to exist on these planets. The implication of this having great effects for our understanding of the foundations of life. Having more than one place where life occurred can indicate what exactly is life allowing for advancements through this knowledge, knowledge that can assist in medicine and ecology.

References:

[1] Siegert MJ, Ross N, Le Brocq AM. Recent advances in understanding Antarctic subglacial lakes and hydrology. 2016; Phil. Trans. R. Soc. A 374: 20140306. http://dx.doi.org/10.1098/rsta.2014.0306

[2] M.R. Siegfried, R.A. Venturelli, M.O. Patterson, W. Arnuk, T.D. Campbell, C.D. Gustafson, A.B. Michaud, B.K. Galton-Fenzi, M.B. Hausner, S.N. Holzschuh, B. Huber, K.D. Mankoff, D.M. Schroeder, P.T. Summers, S. Tyler, S.P. Carter, H.A. Fricker, D.M. Harwood, A. Leventer, B.E. Rosenheim, M.L. Skidmore, J.C. Priscu, the SALSA Science Team; The life and death of a subglacial lake in West Antarctica. *Geology* 2023;; 51 (5): 434–438. doi: https://doi.org/10.1130/G50995.1

[3] Gura, C.; Rogers, S.O. Metatranscriptomic and Metagenomic Analysis of Biological Diversity in Subglacial Lake Vostok (Antarctica). *Biology* 2020, *9*, 55. https://doi.org/10.3390/biology9030055

[4] V.S. Litvinenko, G.L. Leitchenkov, N.I. Vasiliev, Anticipated sub-bottom geology of Lake Vostok and technological approaches considered for sampling,Geochemistry, Volume 80, Issue 3,2020, 125556, ISSN 0009-2819, https://doi.org/10.1016/j.chemer.2019.125556.

[5]Smith, B. M. "Airborne radio echo sounding of glaciers in the Antarctic Peninsula." 1972. https://nora.nerc.ac.uk/id/eprint/509214/1/Airborne%20radio%20echo%20sounding%20of%20glaciers%20in%20the%20Antarctic%20Peninsula%20-%20BAS%20Scientific%20Report%2072.pdf

[6]Yazhou Li, Pavel G. Talalay, Xiaopeng Fan, Da Gong, Bing Li, Yuting Ye, Yue Wang, Ting Wang,Heat transfer modelling of thermal anti-freezing method for ice hot-point drilling, Case Studies in Thermal Engineering,Volume 40, 2022; 102508,ISSN 2214-157X, https://doi.org/10.1016/j.csite.2022.102508.

[7] Litvinenko, V. S., N. I. Vasiliev, V. Ya Lipenkov, A. N. Dmitriev, and A. V. Podoliak. "Special aspects of ice drilling and results of 5G hole drilling at Vostok station, Antarctica." *Annals of Glaciology* 55, no. 68 2014; 173-178. https://www.researchgate.net/profile/Vladimir-Litvinenko-4/publication/275062195_Special_aspects_of_ice_drilling_and_results_of_5G_hole_drilling_at_Vostok_station_Antarctica/links/5e5f9101299bf1bdb850d9eb/Special-aspects-of-ice-drilling-and-results-of-5G-hole-drilling-at-Vostok-station-Antarctica.pdf

[8] Rogers SO, Shtarkman YM, Koçer ZA, Edgar R, Veerapaneni R, D'Elia T. Ecology of Subglacial Lake Vostok (Antarctica), Based on Metagenomic/Metatranscriptomic Analyses of Accretion Ice. *Biology*. 2013; 2(2):629-650. https://doi.org/10.3390/biology2020629

[9] Bulat SA. Microbiology of the subglacial Lake Vostok: first results of borehole-frozen lake water analysis and prospects for searching for lake inhabitants. 2016; Phil. Trans. R. Soc. A 374: 20140292.

http://dx.doi.org/10.1098/rsta.2014.0292
[10] Fox D. “The hunt for life below Antarctic ice”. 2018; https://salsa-antarctica.org/wp-content/uploads/2018/12/The-hunt-for-life-below-Antarctic-ice.pdf