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Melting glaciers, emerging pandemics?

By Adarshini Chandrakanth

Abstract

The world contains over 198,000 to 200,000 glaciers, covering in total over 726,000 square kilometers of Earth's surface (Davies; "Glacier Quick Facts"). The repetitive cycle of snowfall forming layers and compressing into ice sheets over the course of centuries has allowed the formation of these unique, massive masses of ice. Apart from being huge reservoirs of water, glaciers are also hosts of many interconnected microbiomes, fostering active and dormant bacteria, fungi, viruses and other extremophiles. During the Last Glacial Maximum (LGM), or the peak of the ice age around 23,000-19,000 years ago, the sea surface temperature was at its lowest accompanied by low atmospheric Carbon Dioxide (CO2) concentration ("How Does Present Glacier Extent"; Quamar et al.). This was when glaciers covered over 32% of Earth's total surface.

However, today, glaciers account for just around 10% of land ("Glacier Quick Facts"). The rise of human choices, especially our indulgence in activities like industrialisation, consumerism and wastage have contributed to the emission of greenhouse gasses, which has in turn led to global warming. A consequence of this phenomenon is the melting of glaciers. Melting glaciers not only results in the release of water and rising sea levels, but also the unveiling of previously trapped microbiomes. This raised the hypothesis that melting glaciers, and other sections of the cryosphere can expose previously frozen, potentially pandemic-causing pathogens to the world. This descriptive research paper will serve the purpose of encapsulating existing research regarding whether the disintegration of the cryosphere can cause pandemics.

Introduction

Extreme conditions are those in which one or more physical parameters—namely temperature, pH, salinity, pressure, radiation, moisture, nutrients, and chemicals—are on either extreme of the concerned spectrum. By human definition of habitable circumstances, pH should typically be neutral, the temperature should be 68° Fahrenheit (“Best Thermostat Temperatures & Settings for Summer & Winter”), with easy access to water, and various nutrient groups like carbohydrates, proteins, and lipids. Glaciers’ extreme conditions are often interpreted as unfavorable to accommodate life, but extremophiles prove this invalid. Extremophiles are microorganisms that have developed adaptations, or mechanisms to thrive in extreme conditions. Some of Earth’s extreme environments like hydrothermal vents and hot springs are inhabited by extremophiles like chemolithotrophs, or organisms that utilize inorganic substances and chemicals to synthesize energy and sustain life. Similar to the existence of a microbiological world in sweltering heat, freezing cold conditions can also foster life.

Glaciers are an extreme environment similar to hydrothermal vents. Glaciers are large bodies of ice, snow, rock and other substances. They form over the course of centuries through the cycle of snowfall and compression. As the snow accumulates, snowflakes begin transforming into snow grains (which can be equated to frozen drizzle). The weight of snowfall atop of the grains causes the grains to grow into larger crystals. As the mass undergoes various melting seasons, it becomes further dense, leading to the formation of a layer called firn. As more layers of snowfall amass, the layers beneath are made compact and minimal air bubbles are left. However, since fresh snow is made up of around 90% air (Shaw), the glaciers would still have some amount of air trapped within them.

Microbiomes in Glaciers

Glaciers are at the intersection of various extreme conditions, like temperatures reaching down to -40° Fahrenheit (Raikar), with a wide pH range of 6-9 (supraglacial ecosystems’ meltwater runoff can be within the range of 4-10) (Bagshaw et al.). Despite the extreme conditions, the layered formation of glaciers facilitate the introduction, survival and growth of microbiomes. Glacial ecosystems can be divided into three main categories: englacial, supraglacial and subglacial ecosystems. Supraglacial ecosystems are those found on the top-most surfaces of glaciers. These surfaces have access to sunlight and oxygen, leading them to stimulate the growth of photo-autotrophic organisms. This surface includes larger organisms, like ice worms, and moss plants. It is commonly known for the phenomenon of “watermelon snow”, or pink-stained snow. This is a sign of the presence of snow algae, scientifically known as Chlamydomonas nivalis.

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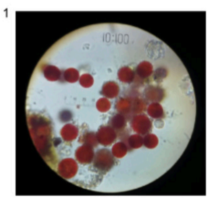

Fig. 8 Cells of snow algae (Sanguina nivaloides) found in the Alps. . . (n.d.). ResearchGate. https://www.researchgate.net/figure/Cells-of-snow-algae-Sanguina-nivaloides-found-in-the-Alps-during-summer-2020-Samples_fig6_355674389

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https://www.gktoday.in/watermelon-snow-update-june-2023/#google_vignette

Chlamydomonas nivalis - Snow Algae

Subglacial ecosystems are found within the ice and snow layers of glaciers. Since these parts of the ecosystem have less access to sunlight and oxygen than supraglacial ones, this ecosystem primarily hosts chemo-autotrophic microorganisms, like Psychrobacter arcticus. Also, pockets of air within the glaciers act as essential sources to promote life in subglacial ecosystems. Primarily, these act as collections of gasses like oxygen and carbon dioxide. Oxygen can allow organisms to aerobically respire, while carbon can make it possible for carbon-fixation to occur. Also, when the layer was still open to the environment, it must have collected dust, pollen and other particulates, which could act as mineral resources to “seed” microbial growth.

Dirt or rocky sediments carried by wind can land upon glacial ice. The dark color of these debris may result in greater absorption of sunlight, and hence it can lead to the specific area of ice to melt. This can result in the formation of cryoconite holes, which are also centers of diverse microbial activity, for the same reasons that air pockets can be beneficial to encourage life growth.

Survival Mechanisms in Glacier Microbiomes

Apart from the method through which microorganisms synthesize energy to sustain life, they also indulge in various other survival mechanisms that allow them to live in the cold conditions of glaciers. For instance, the Psychrobacter spp. bacteria creates antifreeze proteins, or AFPs (Lorv et al.). AFPs are special polypeptides synthesized by psychrophiles that reduce the freezing point of the bodily fluids (cytosol, any other water content) of the cell. They bind to bodily fluids and prevent the crystallization and freezing of the fluids. A variation of AFPs are IBPs, or ice-binding proteins. Fungi and viruses have their own versions of this mechanism, such as producing enzymes that protect from the cold (specific to fungi).

These organisms also take part in nutrient recycling processes, like nitrogen fixation, creation or decomposition of organic matter. An example of this is Cyanophage viruses infecting Cyanobacteria (Srivastava et. al), resulting in the breakdown of the bacteria’s cell membrane (lysis) and eventual death. The dead bacteria acts as organic matter for decomposers (like fungi) to consume. Like how Cyanophage viruses offer other microorganisms dead bacteria to decompose, microorganisms can collaborate and participate in symbiotic relationships to share their resources. The epitome of a symbiotic relationship are lichens, organisms formed through the symbiosis of fungi and algae (or cyanobacteria). Threads of fungi provide structural integrity, while algae supports the energy requirements through photosynthesis. These organisms can survive in supraglacial ecosystems.

Another practiced survival mechanism is dormancy. Dormancy is defined as the act of suspending physical functions or being inactive for a set period of time in order to conserve energy. Bacteria and fungi, like Clostridium spp. and wild strains of penicillin release spores of themselves in difficult conditions (Wells & Wilkins). These spores typically have low metabolic and respiration rates, along with reduced enzyme production. In viruses, like Caudoviricetes enter a stage of viral reproduction called the lysogenic cycle (“The Lytic and Lysogenic Cycles of Bacteriophages”). In this phase, bacteriophage viruses use the host bacteria’s DNA to replicate their own DNA, however, they don’t synthesize any proteins. Microorganisms of the supraglacial ecosystem transition into microbial cysts during harsh winters, while the dormancy rates are higher amongst microorganisms in subglacial ecosystems.

Awakening Micro-beasts?

Over the course of the past few years, glaciers, permafrost and other sources of ice are melting at record-breaking rates. According to a satellite observation done in 2019, University of Zurich (Switzerland), 9.6 billion tonnes of glacial ice have melted since the year 1961 (Iberdrola). Antarctica’s ice is melting at the rate of 150 billion tons annually, and Greenland is losing at about 270 billion tons of ice annually (“Ice

Sheets”).

As various glaciated and permafrost heavy regions have been investigated, many century or milenia-old ancient, potentially pathogenic bacteria, viruses and other microorganisms have been detected and resurrected. For instance, scientists discovered Pithovirus sibericum, a giant DNA virus in a 30,000-year-old permafrost sample from Siberia (Morelle). Another instance of bacteria discovery was when Aureobasidium melanogenum, Naganishisa albida, and Rhodotorula mucilaginosa were all identified in Greenland and Svalbard’s Arctic (Perini et al.). Hemolytic bacteria, potentially pathogenic in nature, have also been isolated from Norwegian Arctic samples (Oppegaard et al.). Majority of these organisms have been brought back to life from dormancy post the thawing of the ice, and identification of suitable conditions.

What is even more concerning is that some of these identified, revived microorganisms are multi-drug resistant. For instance, bacteria collected from 3.5-million-years-old permafrost samples from Central Yakutia (Russia), was multi-antibiotic resistant (Kashuba et al.). One of them, a Staphylococcus hominis MMP2 strain, had over 96% of antibiotic resistant genes (ARGs), specifically to “beta-lactams, aminoglycosides, phenicols and MLS (macrolide, lincosamide, and streptogramin B)” (Kashuba et al.). Many of bacterias collected from remote glaciers also have genetic elements that code for resistance against various antibiotics.

The reason as to how these ancient organisms have developed antibiotic resistance when inhabited in a modern host cell is hypothesized to be horizontal or lateral genetic transfer (HGT) (Yarzábal et al.). HGT is when two organisms share genetic material through untraditional means, or means apart from the typical genetic sharing that happens between parent and offspring cells. This must be further investigated, to understand how these microorganisms are evolving for the worse.

Conclusion

Glaciers and other sources of ice, like permafrost, are extremely hospitable to a diverse range of microorganisms, ranging from bacteria to fungi. While we are finding possible ways in which glacial microorganisms can be pathogenic or could be multiple steps ahead of our usage of antibiotics, it is important to note that instances of pandemics emerging from melting glaciers are possible. A trailer of an event like this was the spread of anthrax in Serbia in 2016 (Doucleff). This outbreak was most likely caused by bacteria or viruses released from melting glaciers. While the possibility of resurrected microorganisms being pathogenic is high, what is even more concerning is their ability of being multi-drug resistant, potentially making them superbugs. Further research needs to be carried out on the means through which these ancient organisms share genetic information with each other, allowing them to develop antibiotic drug resistance even in modern hosts.

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