EARTH AND ITS RESOURCES
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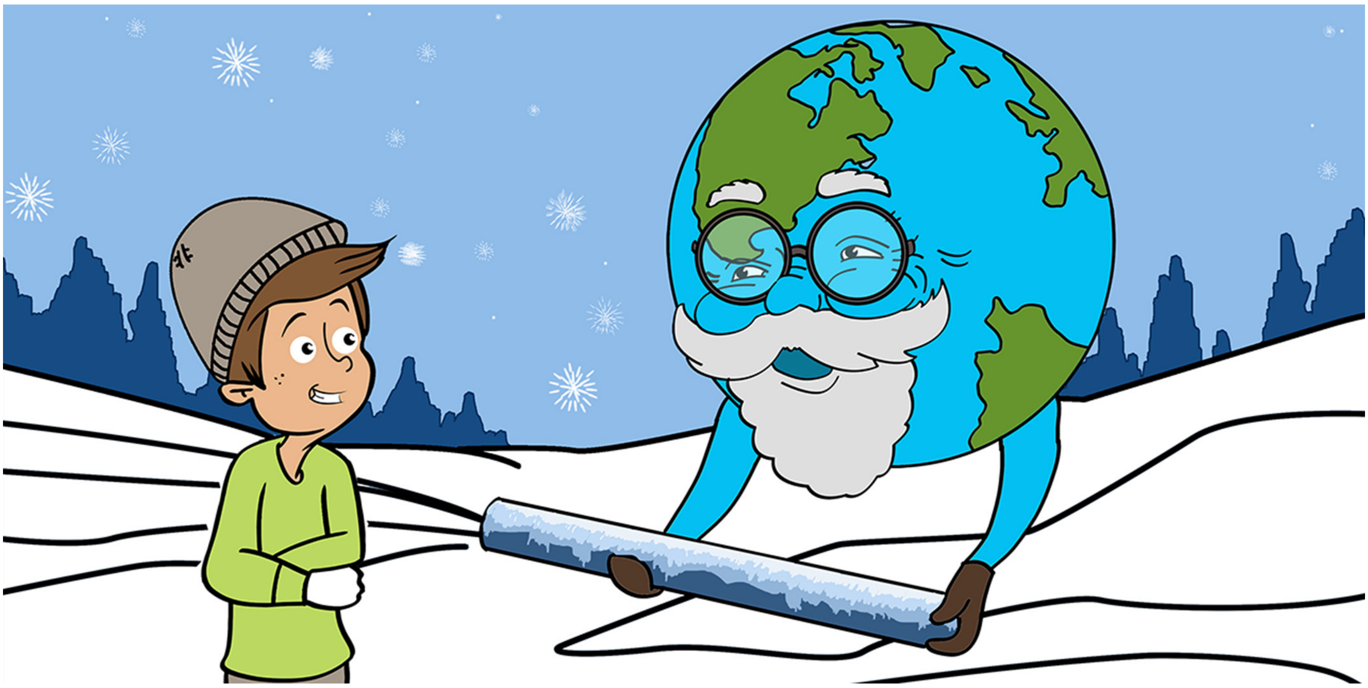

WHAT ICE CORES CAN TELL US ABOUT EARTH'S PAST

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OMER
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The glacial regions of Earth are extremely cold, and snow can accumulate in these regions over tens of thousands of years. Every new snowfall increases the pressure on the snow beneath it, eventually causing it to turn to ice, creating many ice layers. These ice layers contain information about Earth's past at the time when the snow fell. By collecting these ice layers in long cylinders called ice cores, we can examine these layers to see how the Earth's climate has changed over many years and the effects that Earth processes and human activity have had on our planet. Ice cores are unique because much of the information we learn from them cannot be found anywhere else. By complementing ice core information with other information like satellite and weather data and human knowledge and experience, we can learn even more about Earth's past.

HOW IS EARTH'S PAST RECORDED IN ICE?

Earth has two **polar regions**. The northern polar region is called the Arctic (where polar bears live) and the southern polar region is called

POLAR REGIONS

Surrounding the North and South poles, these regions lie within the polar circles and are some of the coldest places on Earth.

Antarctica (where penguins live). These regions receive less sunlight than other places on Earth. With little sunlight, the Arctic and Antarctic are extremely cold places. So, when it snows, there is not enough warm sunlight to melt all the snow and it accumulates over time. As new snow falls, it pushes the old snow farther down from the surface, increasing the pressure it is under. This pressure causes the snow to turn into ice. Every new snowfall eventually becomes an ice layer. Similar ice layers also form in alpine glacial regions like the Rocky Mountains and the Himalayas. These ice layers contain information about the Earth's climate, processes, and human activity at the time of the snowfall. We can examine this information by collecting ice cores [1].

WHAT IS AN ICE CORE AND HOW DO WE COLLECT ONE?

ICE CORE

A long column of ice containing many compacted layers of snow that have accumulated over time.

An **ice core** is a long column of ice made up of many ice layers that have accumulated over time with every snowfall. To collect an ice core, a drill is used to cut a long, deep, vertical hole in the ice. The drill is powered by hand or by a motor and is made of a hollow tube, so when it is pulled up from the hole it contains a long column of ice. Some drills can cut holes over one kilometer deep, but our lab collects mostly shallow ice cores that are about 25 m deep (the length of a swimming pool) and 9 cm in diameter. Sometimes we collect intermediate-depth ice cores that are about 200 m deep (the length of eight swimming pools). The ice core is drilled and collected 1 m at a time, so for a 25 m core, we will have 25 one-meter ice core segments. Shallow ice cores may contain ice-layer accumulation ranging from a few years to many decades, as they are close to the surface and represent more recent snowfall events. Figure 1 shows the basic steps in collecting an ice core. As you can see, collecting ice cores involves working in extremely cold temperatures! Ice core scientists must be equipped with special gear, like glacier glasses and warm suits, to perform their work safely.

Once the ice core has been collected, measurements such as length, weight, and temperature are recorded right away. The segments are then carefully packaged in long plastic bags, which are placed in insulated boxes and packed with snow to keep them from melting in transit. The boxes are shipped to our lab at the University of Alberta. We store them in our −36°C freezer until we are ready to analyze them. Ice cores can tell us stories of how the Earth's climate has changed over many years and the effects that Earth processes and human activity have had on our planet. Evidence of these events in the ice core might be visible to the naked eye, but they often require a closer analysis at the molecular level, using special laboratory equipment.

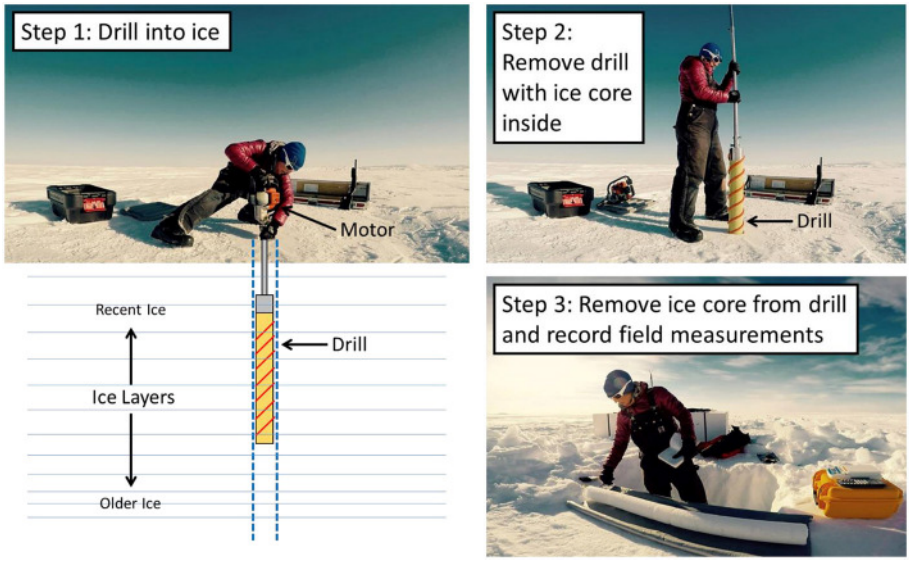

Figure 1

Basic steps of drilling a shallow ice core. Pictures taken during a 2016 expedition on Agassiz Ice Cap, Ellesmere Island, Arctic Canada. (Photo credit: David Burgess).

EVIDENCE OF A CHANGING CLIMATE

When we look at an ice core, we can often see dense layers that represent seasonal changes and snowfall. Near the top of the core, where annual layers are thickest, these layers are sometimes used to count the number of years present in the core [1]. As we go deeper into a core, the layers become compressed and each year is represented by a smaller and smaller part of the core, at which point we cannot see annual layers with our eyes—but we can use the ice core's chemistry to date those compressed layers! Glacier ice can contain cloudy bands that appear white when the ice is cut very thin and polished. Such layers generally contain impurities like dust, soot, ash, pollutants from human activity, and particulates from forest fires. The size of the **ice crystals** is smaller in ice containing more impurities, because impurities prevent the formation of larger crystals (Figure 2).

ICE CRYSTALS

Frozen water that demonstrates geometric patterns.

Layers become blurred when **melt layers** occur. This happens when surface snow melts and drips down into the snowpack below (Figure 2). Upon refreezing, it forms an ice layer with few bubbles. Scientists have observed an increase in melt layers in the Canadian Arctic in recent decades, suggesting that Earth's climate is warming [2]. Though melt layers can change the chemistry of an ice core, oftentimes they only redistribute water and alter the chemistry within 1 year, so the ice-core records are still useful. Nonetheless, a warming climate is certainly a concern to ice core scientists, and some glacier archives are in danger of being lost due to melt. The Ice Memory Project is a program focused on obtaining ice cores from glaciers that are threatened by climate change—places where these invaluable climate records may be lost forever if ice cores are not retrieved now.

MELT LAYER

Surface snow that has melted, dripped into the snowpack beneath, and refrozen, resulting in a dense ice layer with very few air bubbles.

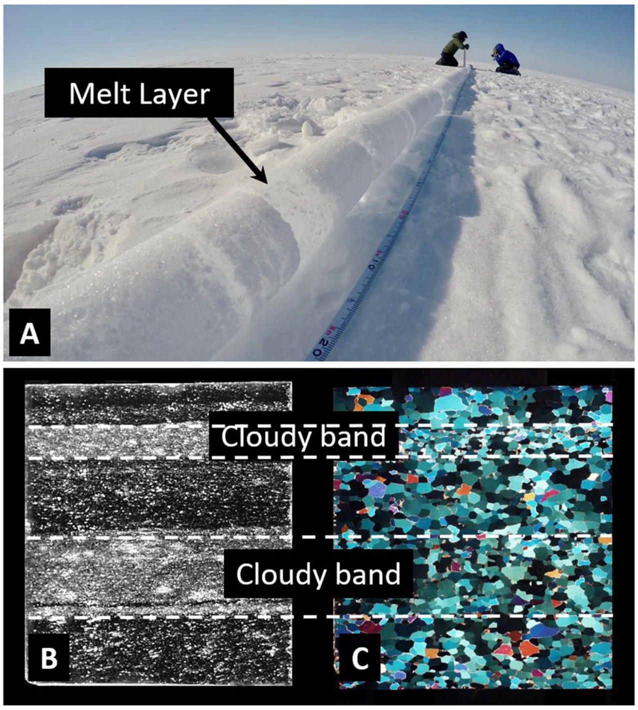

Figure 2

Figure 2

(A) Melt layers visible in an ice core on Devon Ice Cap, Canadian High Arctic. **(B)** Layers seen in a glacial ice sample using a microscope, showing horizontal cloudy bands formed from compacted snow containing a lot of impurities, such as dust from spring dust storms. **(C)** Using special filters on the microscope, we can see that the crystals are smaller within the cloudy bands that have more dust in them. The different colors indicate different orientations of the individual ice crystals. [Photo Credits: **(A)** Alison Criscitiello; **(B,C)** Center for Ice and Climate, Niels Bohr Institute).

In addition to the information we obtain from the ice itself, scientists can also look at gases that are trapped in air bubbles within the ice. These gases give us a glimpse into the past composition of the atmosphere, including concentrations of greenhouse gases, over many hundreds of thousands of years [3].

EVIDENCE OF EARTH PROCESSES

Volcanic eruptions emit large amounts of ash particles and acidic gases to the air. These particles and gases can travel long distances through the air and deposit themselves in polar regions. By examining ice layers for ash and acids, we can identify when volcanic eruptions happened in the past (Figure 3). By examining the chemical make-up of the ash particles, scientists can sometimes even identify which volcano they came from [1].

EVIDENCE OF HUMAN ACTIVITY

POLYCHLORINATED BIPHENYLS (PCBS)

Human-made toxic chemicals once used in various industrial processes, and now an environmental contaminant of concern.

Human-made chemicals, which do not exist naturally, have been observed in ice cores. Some of these chemicals can travel to polar regions through the air from areas where people live and use them. **Polychlorinated biphenyls (PCBs)** are one example. These chemicals were used in electrical equipment such as insulators between 1929 and the 1970s. When scientists discovered that PCBs were being released and contaminating the environment, we stopped making

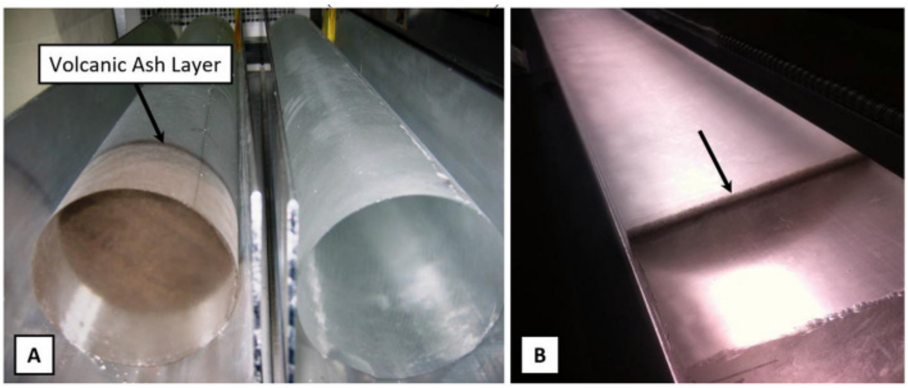

Figure 3

Figure 3

A 22,000-year-old volcanic ash layer in an ice core from the West Antarctic Ice Sheet, which came from a volcanic eruption below the ice in West Antarctica. **(A)** The core just after being drilled in West Antarctica. (Photo: Alison Criscitiello) **(B)** The core after being cut in half at the U.S. National Ice Core Lab. (Photo: Peter Neff).

them. In an ice core from Svalbard, Norway, scientists found that PCB levels decreased between 1983 and 1998. This showed that phasing out industrial production of harmful human-made chemicals like PCBs reduces the impact of human activity on remote polar regions [4].

Evidence of nuclear weapons testing performed between 1945 and 1980 has also been observed in ice cores. This testing released an element called **plutonium** into the atmosphere. Following the testing, some of the plutonium stayed in the atmosphere for years before being deposited in polar regions. Ice core layers containing high levels of plutonium match time periods when we know nuclear weapons testing was occurring [5]. These layers containing high amounts of plutonium are used to assign dates to ice core layers, allowing scientists to compare ice cores from different regions.

PLUTONIUM

A radioactive chemical element.

WHY DO THE STORIES ICE CORES TELL US MATTER?

Much of the information we learn from ice cores cannot be found anywhere else. Ice layers dating back tens of thousands of years, or even 100 years, are sometimes the only evidence we have of Earth's changing climate, processes, or human activity. For example, 50,000 years ago, humans did not have satellites recording details and pictures of volcanic eruptions. But a volcanic eruption at that time may have deposited ash and acid on surface snow that was eventually buried beneath thousands of years of snowfall, preserving an ice layer that can now tell us about that volcanic event. In a more recent example, many human-made chemicals were not known to be harmful to the environment until after they were widely used. Evidence of PCBs in ice layers from the last 70 years tells us when these chemicals first started contaminating our remote polar regions.

While these examples highlight the unique information ice cores can provide on their own, ice core stories are most powerful when they are combined with satellite and weather data, human knowledge and experience, and other information. Such complementary data include, for example, satellite observations of things like sea surface temperature and winds, and automatic weather station data such as relative humidity and temperature. Together, all this data along with ice core information can tell us about how changes in the environment are captured by, and influence, nearby glaciers or ice sheets. Just like a puzzle, we cannot know the whole picture until all the pieces come together. Therefore, ice core scientists often collaborate with experts in other subjects, from chemists to oceanographers to people living in some of these remote cold regions.

ICE CORES TELL US ABOUT EARTH'S PAST, BUT WHAT ABOUT THE FUTURE?

Examining the patterns that we see in ice cores can tell us about the effects that changing climate, Earth processes, and human activity have had on our planet. Scientists can use these past patterns to create **scientific models** that help them predict what might happen in the future. For example, if we see that the number of melt layers in an ice core has increased over the last 25 years, we may be able to predict that a warming trend will continue into the future. Scientific models can be very complex because they must include lots of information to best predict future outcomes. Ice-sheet models, for example, require data about temperature, precipitation, and other factors to help us predict the future of certain glaciers and ice sheets. Atmosphere-Ocean General Circulation Models use relevant energy sources (e.g., radiation, latent heat) and many other data sources to help scientists forecast weather and future climate. Using scientific models, the stories that ice cores tell us about the past can help us to understand our future. Understanding what might happen to the Earth and its climate in the future is the first step toward making changes today—changes that will help us to protect our planet and the living creatures that call it home!

SCIENTIFIC MODEL

A physical, mathematical, or conceptual representation of a real system or process that is difficult to observe directly.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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I like to read history and geography books, comics and manga, and play Pokemon games and other Nintendo Switch games. I am curious and like to learn new stuff.

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Alison is the director of the Canadian Ice Core Lab (CICL) at the University of Alberta. She earned a B.A. in earth and environmental science from Wesleyan University, an M.A. in geophysics from Columbia University, and the first Ph.D. in glaciology ever given by MIT. Being both an ice-core scientist and a high-altitude mountaineer allows her to drill ice cores in some cold and high places! She applies her deep love of Earth's frozen parts to all that she does. Outside of drilling ice cores, she enjoys backcountry skiing, ice climbing, triathlon, playing the mandolin, and being outside with her family.