ANTARCTIC PENINSULA PROGRAM EDUCATION MODULE 1

Photosynthesis, Decomposition and the "Buried Carbon" Hypothesis

BIG IDEAS

1. Plants store energy in organic molecules, and this energy is released when the plants decompose (or are eaten).
2. Organic matter can be covered as glaciers advance and re-exposed when they retreat, thus preserving organic matter from decomposition for vast time periods.
3. When organic matter is re-exposed after deglaciation, release of carbon dioxide during decomposition can add to Earth's greenhouse gases. This is sometimes called the "buried carbon hypothesis."
4. Burial of organic matter during glaciation and re-exposure during glacial retreat form parts of "feedback loops" that influence climate patterns.

INTRODUCTION

In most ecosystems on land or in water, life ultimately depends on **photosynthesis** - the conversion of carbon dioxide (CO_2) and water (H_2O) into simple sugars, such as glucose ($C_6H_{12}O_6$), using light captured from sunlight to create energy-storing compounds. We can summarize this as:

$$CO_2 + H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + O_2$$

Plants can convert simple sugars into more complex forms of carbohydrates, such as starches and cellulose. Plants store energy in starches, such as potatoes or wheat, and animals can obtain this energy for their needs when they feed on plants. Plants often form body structures, such as blades of grass or tree trunks, in the form of cellulose. Cellulose consists of "$C_6H_{10}O_5$" units linked in long chains from several hundreds to many thousands.

$$– C_6H_{10}O_5 – C_6H_{10}O_5 – C_6H_{10}O_5 – C_6H_{10}O_5 – C_6H_{10}O_5 – C_6H_{10}O_5 – C_6H_{10}O_5 –$$

Energy for metabolism (all the biochemical processes in organisms) can be obtained in the reverse biochemical process in which sugars or more complex carbohydrates react with oxygen to form CO_2 and H_2O. This part of the Carbon-Oxygen Cycle is known as "respiration," and provides the energy for all organisms, including you.

$$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O + \text{energy for metabolism}$$

A similar process occurs when a plant dies and decomposers, such as bacteria, break down the complex carbohydrates that remained in the plant body. Decomposition releases CO_2 and H_2O into the air or soil. Careful study of the chemistry involved reveals that breaking the bonds that held atoms together in the carbohydrate also releases energy as heat, which goes into the air.

$$\text{"}C_6H_{12}O_6\text{"} + O_2 \rightarrow CO_2 + H_2O + \text{heat energy}$$

In polar regions, some decomposer bacteria are able to carry out their functions even at temperatures well below freezing. The heat generated by their initial actions in breaking down carbohydrates then provides more suitable conditions for other decomposers that require higher temperatures.

In much of the high latitudes, the dominant climate type is **tundra**. Tundra is characterized by treeless plains, low temperatures, little precipitation, and short growing seasons. Plants include lichens, mosses, grasses, sedges, low shrubs, and some flowering plants. Drainage is often poor, forming ponds and bogs. Decaying organic matter is a major source of energy and nutrients.

Not far beneath the surface is the **permafrost** layer, a zone of permanently-frozen subsoil consisting of gravel, sand, ice, and organic matter. Temperature fluctuations can significantly impact the permafrost zone, which has raised many concerns as more investigations are conducted into possible impacts of climate change. Under ordinary conditions in the tundra, photosynthesis, respiration, and decomposition generally occur in a balance.

But consider what might happen when the tundra becomes buried beneath an ice sheet, such as those that advanced during the last Ice Ages? Or what might happen when organic matter that had been buried beneath the ice again becomes exposed to air as the glaciers retreat? These are some of the problems that Dr. Ning Zeng explored on King George Island as Wilderness Research Foundation's principal investigator.

DR. ZENG'S "ABSTRACT"

An "abstract" is a brief summary of what is contained in an article. For this activity, you'll need to read the abstract from the preliminary expedition report, "Glacial burial and decomposition of ancient organic carbon: a scientific expedition to King George Island, Antarctica." It was prepared by Ning Zeng (Project Scientist, Associate Professor, University of Maryland, College Park) and Jay Gregg (Junior Scientist, University of Maryland, College Park). Explanations for some of the technical terms will be provided in the activities below.

> An expedition to King George Island (KGI), Antarctica, was conducted during January, 2010. The main goal was to search for ancient organic carbon buried under ice and to understand the role of such organic carbon in glacial-interglacial CO_2 and climate changes. Three trips were taken to study the environment of the Collins Glacier on the southern edge of the KGI icecap. A glacial moraine was found to contain a large quantity of organic carbon. An outcrop was found to contain several clearly distinguishable layers: rubble, soil, moss, soil, shell, moss, muddy soil, and ice. The surrounding area and the glacial outwash downstream contain large amounts of organic material. CO_2 fluxes were measured at two locations using a LICOR-8100 soil CO_2 analyzer, with soil CO_2 fluxes ranging 15-20ppm/30min (0.15 µmol m-2 sec-1). Because there was no observable new vegetation growth on the site, and because the chamber where the flux was measured was dark (preventing photosynthesis), it appears that the CO_2 was the result of the decomposition of the organic carbon that was once buried under ice. Our findings support the hypothesis that organic carbon, including both vegetation and soil carbon, can be buried under ice, and later released back into the atmosphere, thus contributing to climate change through the emission of CO_2, a greenhouse gas.

YOUR CHALLENGES

Imagine you are going to KGI to assist Dr. Zeng and Dr. Gregg with their research. The first thing that you and all scientists do to investigate questions like these is to create a hypothesis—a statement that can be tested by experimentation. Hypotheses often have the form:

"IF something, THEN something, BECAUSE something."

Q1. Based on what you have read so far about photosynthesis and decomposition, write a hypothesis to explain what might happen to organic matter buried beneath glaciers or ice sheets for thousands of years.

Next, try to design an experiment that would test your hypothesis.

Q2. Similarly, write a hypothesis to explain what might happen to organic matter that was buried beneath glaciers and has now been exposed because the climate in that region is warming. Then, design an experiment to test your idea.

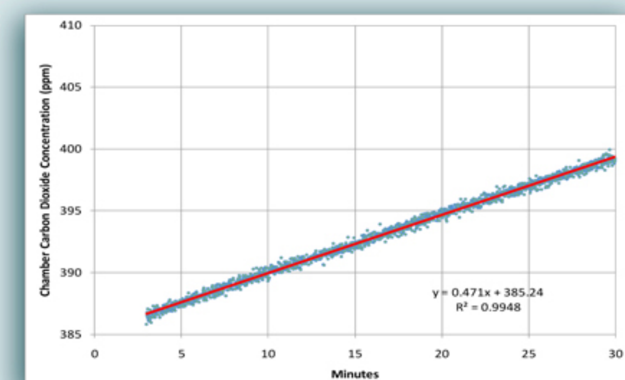
Q3. Using online and print resources, research what soil decomposers are and answer these questions:

A) Where might the soil decomposers originally come from? Explain your answer.

B) Were they also buried by the glaciers and now re-exposed? Explain.

In the abstract, the researchers report that an instrument (LICOR-8100 soil CO_2 analyzer) was used to measure the CO_2 flux (amount of CO_2 passing through the air flow in the machine in a given time period). The average flow was 15-20ppm/30min (0.15 µmol m-2 sec-1). This is read as "15 to 20 parts per million in 30 minutes, or 0.15 micromoles per meter per second. (A mole is a chemistry unit; one mole of CO_2 has a mass of 44 g.)

Here is an example of the data they collected:



Site 1, Spot 1, CO_2 concentration in the chamber increased over time due to bacterial decomposition.

Q4. What are the two pieces of evidence they give which indicates the CO_2 flux results from decomposition and not photosynthesis-respiration?

The measurements support their hypothesis that organic carbon in vegetation and soil can be buried under ice and later released back into the atmosphere, thus contributing to climate change through the emission of CO_2, a greenhouse gas.

Q5. What are "greenhouses gases"? How do they influence Earth's global temperature patterns?

Q6. A) What impact might decomposition of organic matter have on global climate change?

B) Local ecologies in tundra communities?

Other studies have found that King George Island is in one of the most rapidly warming polar regions so far identified.

Q7. Create a hypothesis to explain whether these processes would occur at different rates in other locations which are not warming as fast. Describe your experiment procedure.

"Feedback loops" play major roles in many Earth processes, but often are not well recognized or studied. A "positive feedback loop" occurs when an increase in one factor produces an increase in a second factor. A "negative feedback loop" occurs when an increase in one factor produces a decrease in the second.

Q8. What type of feedback loop exists in the situation studied at King George Island?

Here are factors to consider:

As organic matter is buried during a glacial advance, decomposition (release of CO_2) will {decrease/increase} and temperatures will {decrease/increase}.
This is a {positive/negative} feedback.

As organic matter is re-exposed during a glacial retreat, decomposition (release of CO_2) will {decrease/increase} and temperatures will {decrease/increase}.
This is a {positive/negative} feedback.

CONCLUSIONS FOR THE RESEARCH TEAM

Large amounts of organic carbon in a glacial moraine outcrop and the downstream outwash were found at the front edge of Collins Glacier, King George Island. The organic carbon was deposited in the past as layers of moss, interlaced with shells and soil. This suggests that the area was once at sea level when shells were deposited. There were multiple periods of moss development and sedimentation.

The measured CO_2 flux was significant, indicating comparatively rapid decomposition once the old carbon is exposed. There was no evidence of new vegetation growth around the outcrop where measurement was done. This indicates a relatively fresh exposure, possibly within the last few seasons. These results are intriguing, suggesting that soil organisms (decomposers) are active within newly exposed soil from the glacial moraine. Whether they lie dormant under the ice for millennia, or they are newly transported to the area from somewhere else will be determined by carbon dating the soil. Further work will be undertaken to date the sample to understand the age and developmental history of the organic carbon.

SUMMARY

Write a summary describing the most important ideas you have learned through this activity (2-3 paragraphs) and at least two additional questions emerging from this project that could be the subject of future research.

SPECIAL FEATURE

Scientists at Work: Measuring CO_2 Flux with the LI-COR 8100

Seeking physical evidence for the "buried carbon" hypothesis, Dr. Ning Zeng of the University of Maryland's Department of Atmospheric and Oceanic Science brought to Antarctica the LI-COR 8100 Automated Soil CO_2 Flux System, a sensitive instrument for measuring the CO_2 flux (release into the atmosphere) of samples of recently uncovered glacial moraine soil.

LI-COR 8100

- A sophisticated flux-monitoring instrument, modular and easy to use
- Easily transportable in backpacks in the rugged environmental conditions of KGI
- Offers options of short- and long-term observations

Photo credit: Sheldon Bart

The instrument measures the movement of carbon dioxide through the soil (soil CO_2 efflux), a physical process driven primarily by the difference in concentration of CO_2 in the upper soil layers and the atmosphere directly above the soil. The greater the difference (the steeper the gradient), the faster CO_2 moves out of the soil into the air. The system is designed to cause minimal disturbance to the environmental conditions that have an impact on CO_2 production and transport within the soil profile.

Data Collection on KGI

- Samples collected from two locations in moraine at southern end of Collins Glacier
- No observable new vegetation at sites
- Complete darkness inside chamber prevented photosynthesis
- CONCLUSION: CO_2 was released by decomposition of organic matter once buried beneath the ice.

Jay Gregg sets up the LICOR LI-8100 Automated Soil CO_2 Flux System near Site 1
Photo credit: Ning Zeng

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