Remote teaching of introductory physical geology labs during the covid pandemic

Vince Cronin
Baylor University

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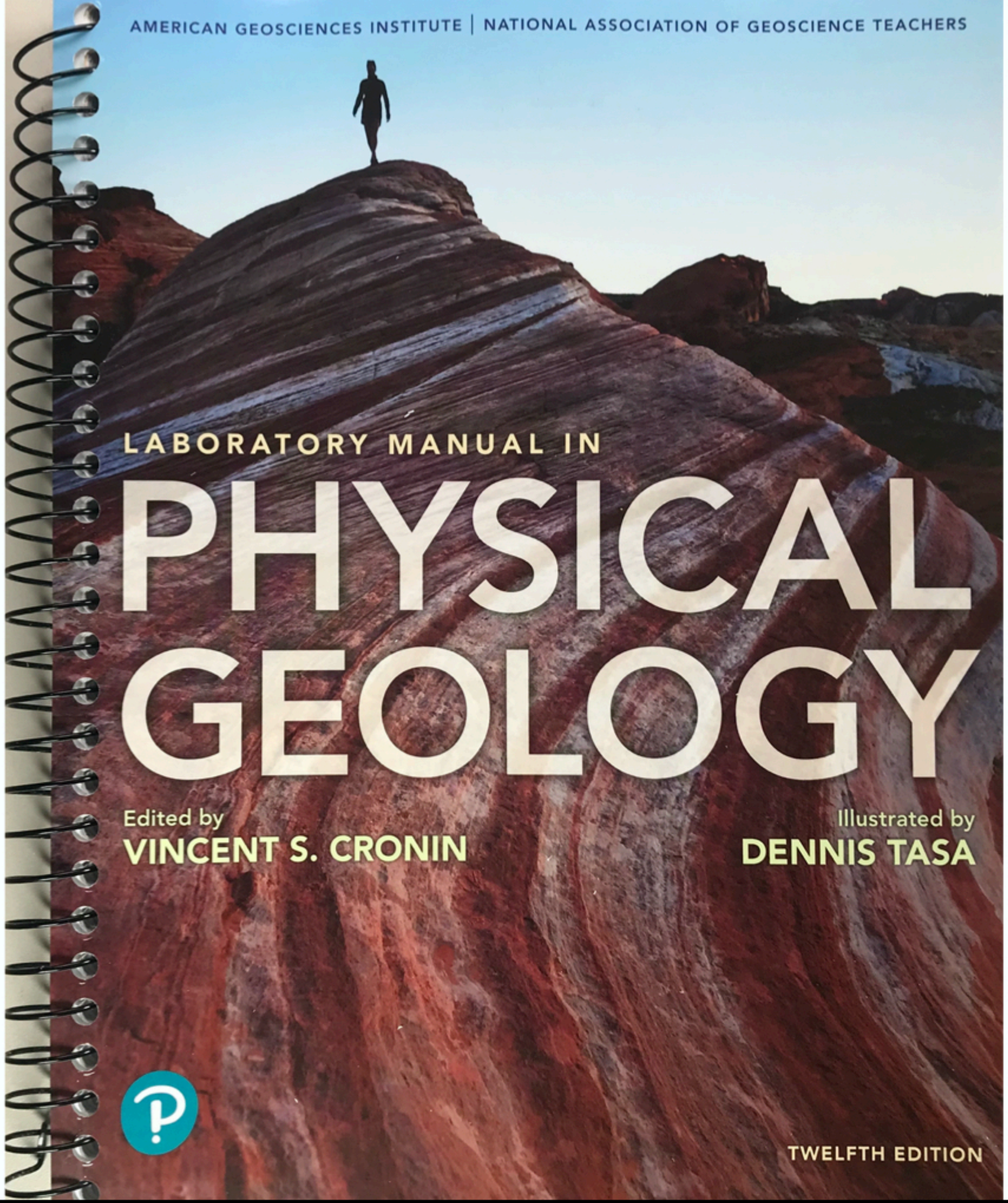
How *Introduction to Phys Geology* Was Taught at Baylor

Term	Style	Cronin's Lecture Section	DiPietro's Lecture Section	All Lab Sections
Early Spring 2020	Traditional	In-Person	— —	In-Person
Late Spring 2020	Flipped	Remote	— —	Remote
Summer 2020	Flipped	Remote	— —	Remote
Fall 2020	Flipped	Remote	Remote	Remote
Spring 2021	Flipped	Remote	In-Person	Remote
Fall 2021	Flipped	In-Person	In-Person	In-Person


Irish
Columbia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LABORATORY MANUAL IN
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Illustrated by
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Flourishing during the pandemic requires human interaction.

Flourishing during the pandemic requires human interaction.

The answer is “kindness” and, when appropriate, add a dash of mercy.

Laboratory 17

Earth's Dynamic Climate

Contributing Author

Mark Carpenter • *American Geosciences Institute*

▲ Ice calving from the terminal face of Perito Moreno Glacier into Lago Argentino, Parque Nacional Los Glaciares, Patagonia, southern Argentina (near 50.467°S, 73.041°W). Photo taken 25 April 2017 by David Wall/Alamy.

Big IDEAS

Advances in science and technology over the past century have enabled us to measure changes in the Earth system, providing us with a strong base of reliable information. Superimposed on the natural rhythms of a planet that has been in an "ice age" for the past ~2.6 million years are extraordinary changes in the chemistry and temperature of the atmosphere and oceans that pose significant challenges to human society worldwide, now and for the foreseeable future. With our expanding knowledge of the history of Earth's climate before human involvement, scientists draw data-based interpretations of the contribution of human activities to global environmental change. Geoscience has an extraordinary opportunity to contribute to the health and welfare of both human society and the Earth ecosystem by continuing to provide reliable information and informed advice to a growing global community so that, together, we can navigate toward a more sustainable and just future.

Lab ACTIVITIES

Pre-Lab Video 17
http://goo.gl/NrcXgB

Introduction

The historical origins of geoscience are linked to two general prerequisites for the physical development of society: the need for essential resources and protection from natural hazards. These remain as fundamental motivations, but our knowledge of Earth systems in general and the vulnerabilities of Earth's ecosystems in particular imparts an added responsibility for geoscientists to act as stewards of the Earth environment. Among the many contributions of geoscience to society, our enhanced understanding of our place within Earth's dynamic and interdependent natural systems can help society make good choices in moving toward a healthy and sustainable future.

Change is a consistent theme throughout geoscience because the Earth system is an interconnected web of subsystems transferring ***energy*** and ***matter*** across a vast range of scales in time and space. Earth's climate variability illustrates the dynamic nature of our planet. The image in Fig. 17.1 was acquired using the MODIS instrument on NASA's *Aqua* satellite, orbiting 705 km above Earth. At the top of the image, Alaska is part of the North American Plate, moving slowly across Earth's surface. The Pacific Plate, under the spiraling cloud systems, is subducting under Alaska along the Aleutian Arc. The seawater of the Pacific Ocean moves much more rapidly than the lithosphere in response to tides, gyres and currents, and an atmosphere to which it is intimately linked. The energy source responsible for the moving seawater and atmosphere are Earth's rotation and the Sun. The moist atmosphere above the Pacific spins and flows at an even greater rate than the seawater as it carries heat, water vapor, various gases, tiny solid particulates, and storms large and small across the surface. In addition, life is an integral part of the Earth system.

The physical and chemical laws that control these systems are constant, but their effects result in an ever-changing world. We use the methods of science to measure these changes, to develop understanding of the processes that cause them, and to recognize or predict the physical effects of these changes. Earth's climate system has a natural variability that operates without human involvement, and that variation over time has left a geological imprint that we can interpret. During Earth's long history, climate has shifted many times, and each time it moves toward a new and temporary state of ***equilibrium***. Augmenting this natural variability, human activities have begun to have a significant effect on climate.

Homo sapiens evolved from and along with other hominins, first appearing as a distinctive form sometime between 300,000 and 200,000 years ago. It took until about 1804 CE for the living human population of Earth to reach

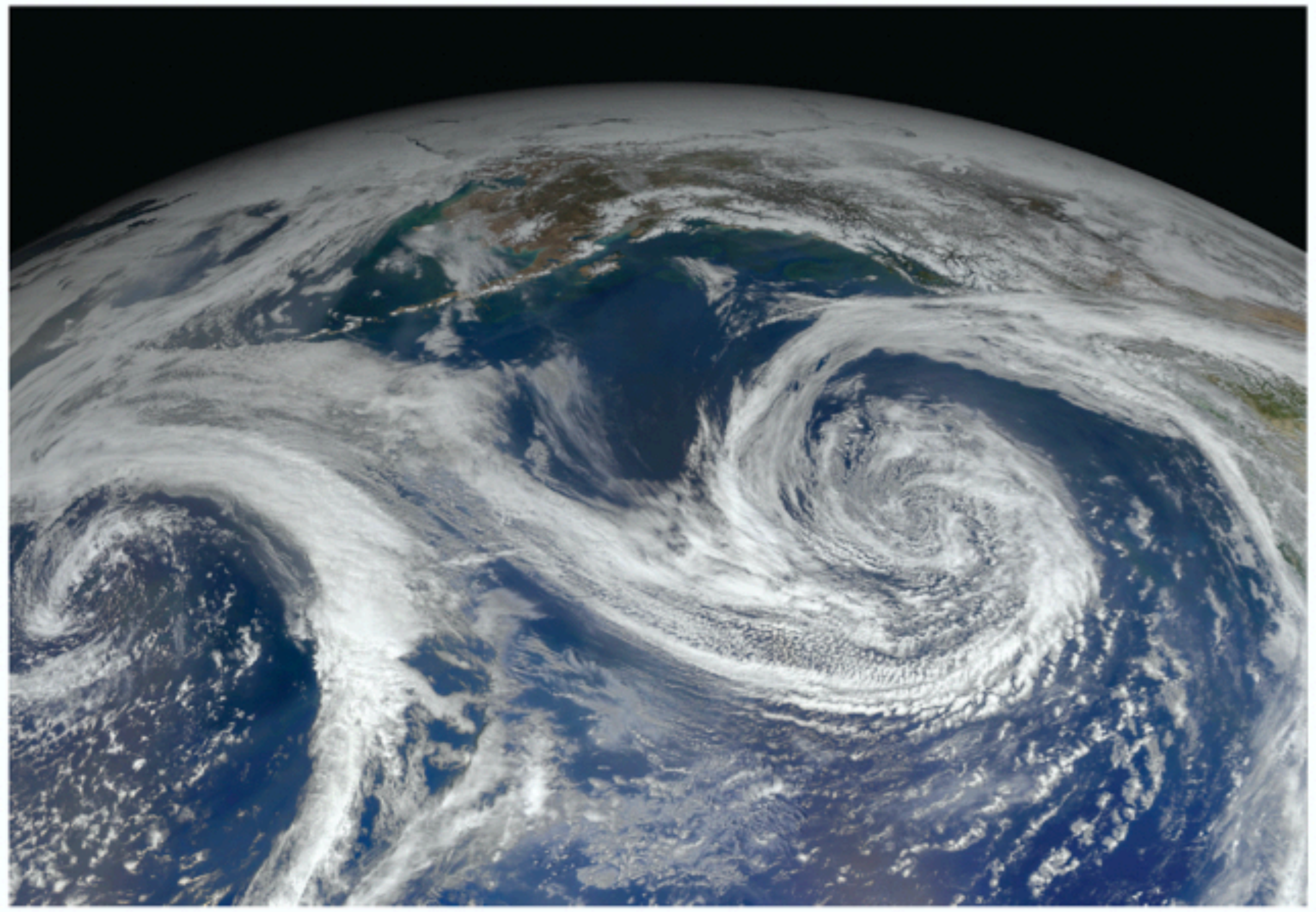


Figure 17.1 **Dynamic Earth.** Storms in the Gulf of Alaska as imaged May 2, 2014, using the MODIS instrument on the *Aqua* satellite. Photo: NASA Earth Observatory, https://earthobservatory.nasa.gov.

1 billion individuals. As this sentence is being written in mid-2019, the living human population is just over 7.7 billion, having tripled in the past ~75 years. Various modelers speculate that the human population of Earth will plateau somewhere between 10 and 12 billion in the next century or two because of factors such as resource limits, declining fertility, and possible changes in life expectancy.

Beyond the capacity for humans to propagate, our intelligence and ability to transform raw natural resources into machines capable of doing useful work has, to some extent, put us into a separate category within the biosphere. We can use tools and machines to modify the land surface: planting and cutting down vast swaths of forest, modifying coastlines, creating lakes and diverting rivers, devoting huge areas to crop production, concentrating populations in the built environments of cities and towns. We generate a lot of waste in the process—solids, liquids, gases—and some of this waste is toxic or difficult for natural systems to absorb. Humans are significant agents of environmental change.

Each person requires food, potable water, shelter, space, energy, and interaction with others to survive and seeks secure access to all of these necessities. This is as true for a person born in New York City as for people born into communities in the African Sahel, on a low atoll in the Pacific, in the mountains of central Asia, or along a coastline in the Arctic. An increasing global population poses obvious social and political challenges, but it also involves difficult issues of justice in the supply and distribution of necessary resources. It seems evident that the global community needs to move toward greater sustainability in our resource use, waste handling, agricultural and land-use practices, and energy supply.

A significant part of the energy we used to power our machines during recent centuries came from stores of carbon in the form of coal, oil, and natural gas that were long buried beneath Earth's surface. Coal was introduced in London as a fuel for lime kilns and forges by 1228 CE and was banned by King Edward I in 1306 to curb the negative health effects of air pollution. The ban lasted only a couple of decades because coal generates more energy when burned than an equal amount of wood, and plentiful supplies of coal existed just up the coast in Newcastle. Worldwide since the Middle Ages, mining this carbon and using it to generate power through combustion has significantly increased the amount and rate of ***carbon cycling*** from the geosphere's stores through the atmosphere and oceans. The benefit to society has been to provide a flexible, transportable, and generally inexpensive source of energy that has made the development of a technology-enabled modern world possible. According to a study published by British Petroleum in early 2019, more fossil fuels were produced and consumed during 2018 than in any previous year in human history. The costs of this increased carbon in the environment, particularly since the industrial revolution in the 1800s, are now becoming evident.

Scientists learn about the world by collecting reproducible observations, assessing the uncertainty of those data, and developing testable hypotheses that relate these observations to one another. Geoscientists contribute to society by providing reliable information about Earth and by helping society understand the meaning and consequences of this information. An important thing we have learned is that human activities have an effect on the natural variability of Earth's climate, in terms of both the rate and magnitude of change, and that the effect seems to have become significant.

The purpose of this laboratory is to give you an opportunity to learn about and work with a few of the many important types of scientific information that we use to monitor and model Earth's dynamically changing climate and to consider some of the physical consequences of climate change that are of concern to society.

Greenhouse Gases

Irish physicist John Tyndall discovered in 1859 that water vapor, carbon dioxide, and several other gases present in Earth's atmosphere absorb infrared radiation from the Sun and eventually emit similar radiation, resulting in atmospheric warming. Atmospheric gases that have these characteristics are called **greenhouse gases**. In 1895, Svante Arrhenius of Stockholm University demonstrated that increases in carbon dioxide in the atmosphere could increase Earth's surface temperature. The warming of Earth's surface contributed by emissions from greenhouse gases is called the **greenhouse effect**. He speculated that without these greenhouse gases, Earth's surface temperature would drop below freezing and water vapor would be greatly reduced if not eliminated in the atmosphere, making Earth colder still. By 1904, Arrhenius recognized that industrial-scale combustion of fossil fuels could increase the atmospheric concentration of CO_2 beyond levels generated by natural processes and he predicted that the surface temperature is likely to rise over the next few centuries. (Reportedly, Arrhenius did not consider a bit of global warming to be unwelcome, working from his base in chilly Sweden.)

Half a century later, another scientist at Stockholm University, Bert Bolin, became interested in the likely effects of rising levels of CO_2 that had already become evident. Bolin became an expert in the **carbon cycle**—one of the most fundamental cycles in the Earth system (**https://www.earthobservatory.nasa.gov/features/CarbonCycle**). Bolin focused on understanding the contributions of human activities to the atmospheric concentration of greenhouse gases. He worked with other scientists, politicians, and the United Nations to bring his concerns to the public in an effort that led to the creation of the UN Intergovernmental Panel on Climate Change (IPCC) in 1988, the UN Climate Change Convention of 1992, and subsequent international treaties and agreements to protect the Earth environment.

Water vapor is the largest contributor to the greenhouse effect, responsible for ~60% of the warming. However, the amount of water vapor in a given volume of atmosphere is controlled by the temperature of the atmosphere, not the other way around. If atmosphere saturated with water vapor is cooled, some of the water vapor condenses into liquid water. Water vapor does not control atmospheric temperature, but rather its occurrence is caused and constrained by atmospheric temperature. The atmosphere's temperature is controlled by gases that do *not* condense in the atmosphere—mostly **carbon dioxide** (CO_2), **methane** (CH_4), **nitrous oxide** (N_2O), and **ozone** (O_3), and human-made gases such as the **fluorinated gases** chlorofluorocarbons, hydrochlorofluorocarbons, nitrogen trifluoride, and sulfur hexafluoride. Tiny aerosol particles in the air also control the atmosphere's temperature. The warming caused by the increase in non-condensable gases causes an increase in water vapor in the atmosphere, which adds to the warming effect.

Although other gases are more potent greenhouse gases, the most abundant greenhouse gas in the atmosphere other than water vapor is CO_2. Carbon dioxide is produced naturally in a variety of ways, such as cellular respiration, decay of organic waste, wildfires, and volcanic processes. The combustion of **fossil fuels** (coal, oil, natural gas) and the manufacture of cement comprise about 75% of human-controlled emissions of CO_2, with deforestation, agricultural and land-use practices, and livestock making up the rest.

Methane (CH_4) is less abundant, but is roughly 2030 times more potent than CO_2 as a greenhouse gas. Methane is produced naturally by wetlands and decaying organic material in environments where there is little or no free oxygen available—anaerobic environments. Methane does not last as long as CO_2 in the atmosphere, where it breaks down into other compounds over an average of about 8 years. A large volume of CH_4 formed by bacteria on the seafloor is locked in water ice, forming methane hydrates buried under seafloor sediments where the water temperature is about 2°C. Human-controlled emissions of CH_4 occur as a result of the extraction and transportation of fossil fuels as well as by agricultural sources (livestock, rice farming) and the decay of organic waste in anaerobic environments like landfills or thawing permafrost. Thus, Earth's frozen stores of CH_4 not only are sensitive to temperature but have a strong capacity to cause temperatures to rise if released, illustrating the theme of ***positive feedback*** in Earth's climate system.

ACTIVITY 17.1

How Does Rising Temperature Affect Sea Level? (p. 445)

Study the section *Measurement of Global Mean Sea Level* to complete Activity 17.1.

Measurement of Global Mean Sea Level

Since 1992, a series of orbital satellites (*TOPEX/Poseidon*, *Jason-1*, *OSTM/Jason-2*, and *Jason-3*) has been used to measure the elevation of the sea surface, providing near-global coverage. The position of each satellite is accurately determined using three different methods at any given time in a reference frame that is fixed to Earth, and an instrument called a radar altimeter measures the height of the sea surface. The radar altimeter emits a radar pulse that bounces off the sea surface and returns to the satellite, which records the travel time down and back. The travel time indicates the distance between the satellite and the sea surface to within about 1 cm—a measurement repeated thousands of times every second. *Jason-3*, launched in early 2016, is a joint project involving NASA, the National Oceanic and Atmospheric Administration (NOAA), the European Organization for the Exploration of Meteorological Satellites, and France's space agency: the Centre National d'Etudes Spatiales. *Jason-3* takes about 10 days to survey the entire Earth from a height of ~1336 km (830 mi).

The height of a given point on the sea surface changes over the course of seconds to minutes due to waves, hours due to tides, hours to days due to passing weather systems, months due to seasonal variations, and years due to mass and temperature changes related to climate change. Large-scale phenomena like the El Niño-Southern Oscillation also have a major effect on local sea level. Taking these phenomena into account, the near-global coverage of orbital satellites with radar altimeters allows a mean (average) global sea level to be established for any given time period (e.g., daily, monthly, seasonally, annually).

Measuring Ocean Temperature and Salinity

An array of ***Argo* floats** has been deployed, starting in 2000, to automatically measure the temperature and salinity of the upper 2000 m of the world's oceans (Fig. 17.2). Using GPS to track the *Argo* floats, important information about the flow of water in the upper ocean has been collected. The goal is to deploy about 4000 *Argo* floats spaced about 300 km apart to cover most of the ice-free surface of the oceans. With participation from more than two dozen countries worldwide, the *Argo* network included 3878 floats as of mid-June 2018.

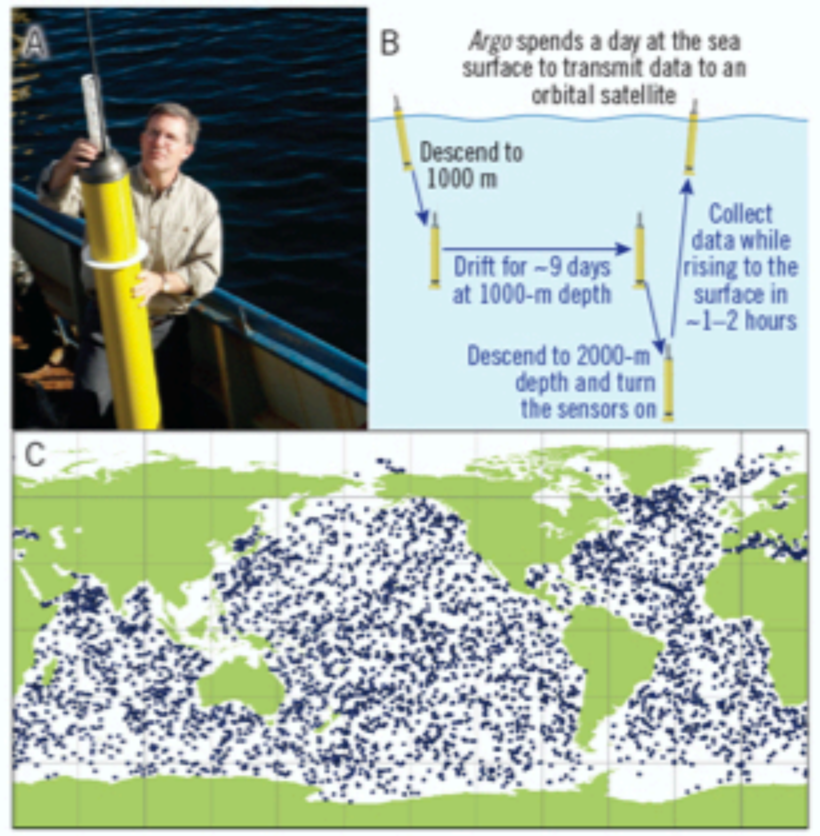


Figure 17.2 *Argo* robotic float. **A.** *Argo* robotic float being prepared for deployment. Photo: Allamy. **B.** The ~10-day cycle of *Argo* drifting, sampling, and reporting on the environmental conditions in the upper 2000 m of the oceans. **C.** Location of 3890 *Argo* floats (blue dots) contributed by 25 nations in May 2019. Map: Argo Information Centre.

In addition to the standard *Argo* robotic floats, new generations of floats collect a wider range of data, including acidity (pH); oxygen, nitrate, and chlorophyll concentrations; and other biogeochemical data. Floats capable of sampling a deeper swath of the ocean, perhaps from the seafloor to the sea surface, are in development.

The *Argo* network provides essential data for understanding the fundamental components of sea-level variation due to changes in temperature and salinity—also called the **stearic component** of sea-level change. *Argo* data is free and available online within about 24 hours of transmission from the float. Current information about the *Argo* Program is available via **http://www.argo.ucsd.edu**.

ACTIVITY 17.2

Melting Ice and Rising Sea Level (p. 448)

Study the section *Adding Water to the Ocean from Melting Ice Sheets* to complete Activity 17.2.

Adding Water to the Ocean from Melting Ice Sheets

If you think about persistent ice on continental crust, images of alpine glaciers flowing down high valleys in the Himalaya, Alps, Rocky Mountains, Sierra Nevada, and other mountain ranges might be the first thing that comes to mind. Although these mountain glaciers are locally important for water supply and other reasons, their volume is far less significant than the volumes of the **Greenland** and **Antarctic ice sheets**. (A similar ice sheet, called the **Laurentide ice sheet**, used to cover the northern part of the North American continent until about 6000 years ago.) Growth of such major ice sheets causes sea level to go down or subside because so much water is stored above sea level in the form of glacial ice. Melting of ice sheets releases this stored water and causes sea-level rise. We can think of global ice mass and sea level as ***coupled components*** of the global hydrological cycle. The water frozen in the Antarctic ice sheet represents an estimated 60–70 m of global sea-level rise, whereas the Greenland ice sheet represents about 7 m.

The elevations of the bedrock on which the great ice sheets on Greenland and Antarctica sit have been mapped using a variety of geophysical techniques. The elevation of the top of the ice sheets is surveyed repeatedly each year, using data from several satellites and aircraft. Knowing the topography of these two surfaces, we can determine the volumes of the Greenland and Antarctic ice sheets and can monitor the change in volume over time (Fig. 17.3). We have good digital maps of the edges of the Greenland ice sheet (**Fig. 17.3A**) and a digital elevation map (**Fig. 17.3B**)—both of which change over time. Radar and other geophysical surveys have provided us with a good map of the upper bedrock surface under the ice (**Fig. 17.3C**), which remains essentially constant for decadal time spans. Combining these maps allows us to determine the volume of the ice sheet (**Fig. 17.3D**).

A more immediate way of detecting changes in the ice volume of an ice sheet is to measure gravity across the ice sheets using orbital satellites. DLR/NASA's *Gravity Recovery and Climate Experiment* (*GRACE*) uses two identical spacecraft moving in tandem about 220 km apart in orbit about 500 km above Earth's surface. The distance from one spacecraft to the other is measured accurately using a combination of GPS and a microwave ranging system. Slight variations in Earth's gravity cause slight changes in the distance between the spacecraft, so this satellite system is an orbital gravimeter. As the *GRACE* satellite system passes over the same spot on Earth, variations in gravity at that spot can be interpreted as variations

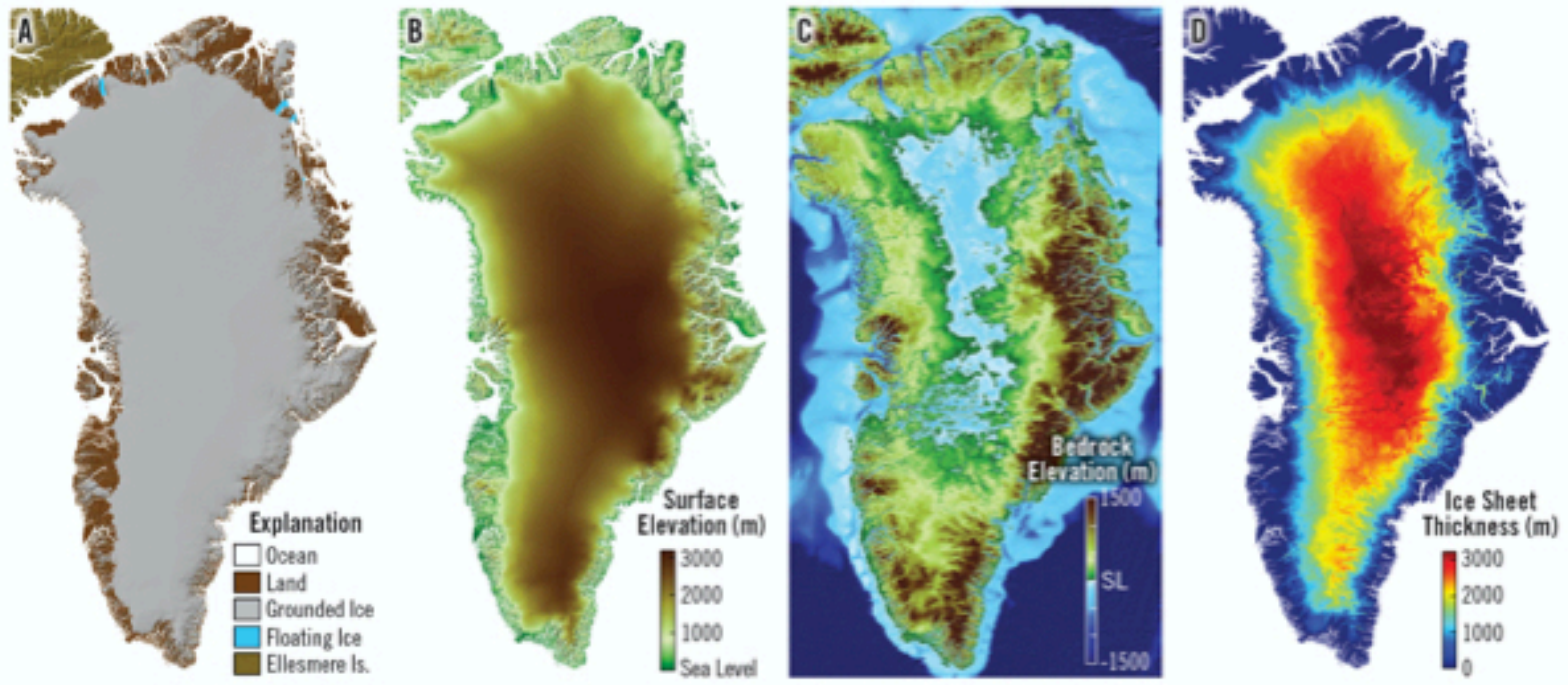


Figure 17.3 Estimating Greenland ice sheet volume. **A.** Extent of the Greenland ice sheet and ice shelves. **B.** Digital elevation model of the upper surface of Greenland, including the top of the ice sheet. **C.** Relief map of the top of the bedrock under the Greenland ice sheet. **D.** Map of the thickness of the ice sheet. Base maps from Morlighem and others (2017).

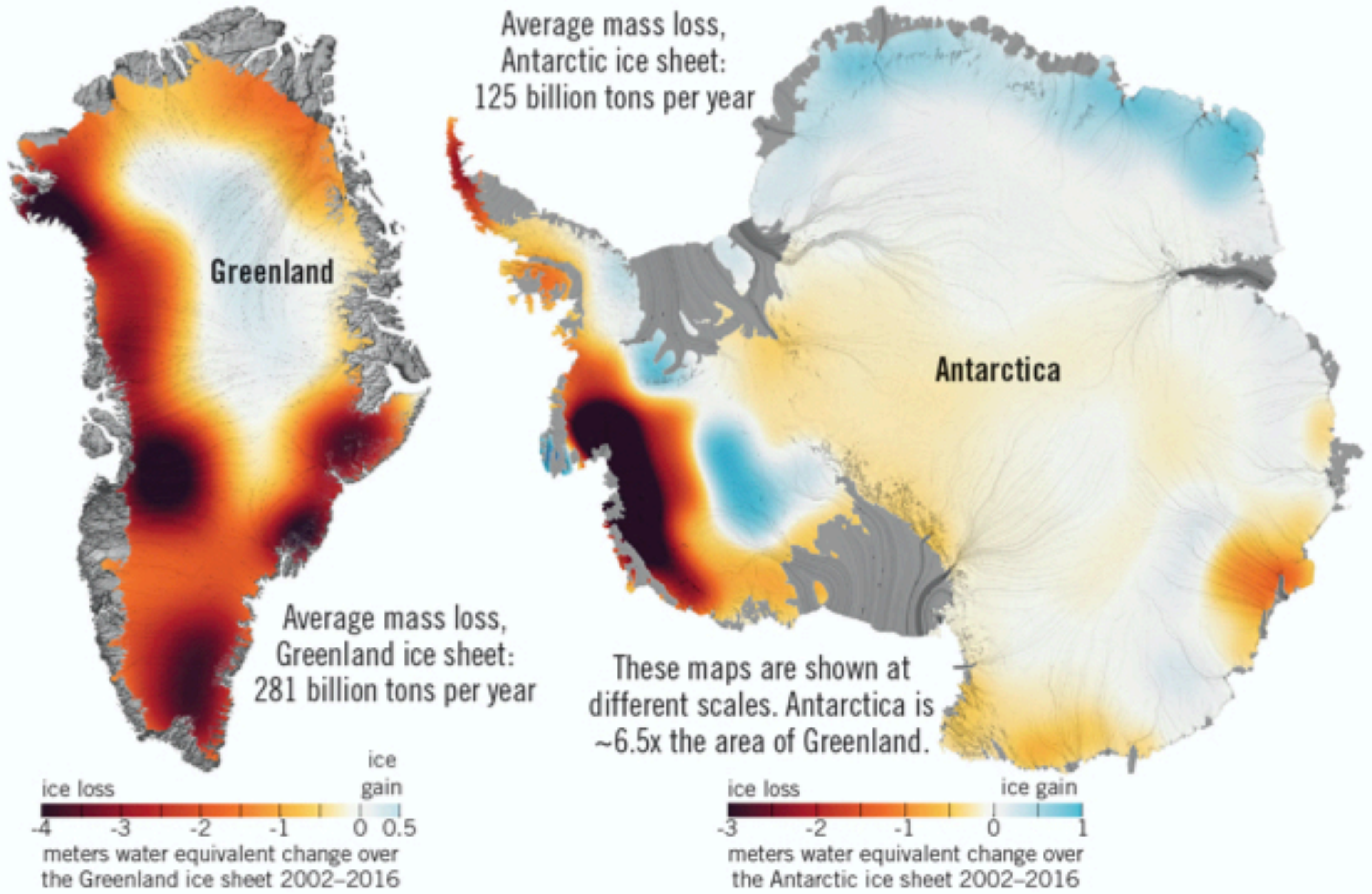


Figure 17.4 Graph of ice mass loss, Greenland and Antarctica. Maps showing changes in ice mass of the Greenland and Antarctic ice sheets between 2002 and 2016, using gravity data from the *GRACE* satellite system. Darker red-brown areas indicate greater ice mass loss. NASA maps.

in mass. As the ice mass on Greenland and Antarctica changes due to accumulation or melting of ice, the acceleration of gravity over these two land masses changes in ways that can be measured.

Scientists have been able to monitor changing ice mass on Greenland and Antarctica since *GRACE* was launched in 2002 (Fig. 17.4). The Greenland ice sheet lost mass at an average rate of 281 billion tons per year between 2002 and 2016, while Antarctica lost 125 billion tons per year. A corresponding amount of cold fresh water was added to the world's oceans, contributing to sea-level rise. Most of the loss on Greenland was around the margins of the ice sheet, particularly in the south and west. Coastal west Antarctica lost the most ice over this time interval, while north and interior-west Antarctica actually gained ice mass.

Local increases in ice mass might be due to the operation of a ***negative feedback*** in which warmer seawater causes increasing evaporation from the ocean surface, increasing water vapor in the atmosphere. Colder air over the Antarctic ice sheet causes the water vapor to condense and form snow. New white snow on the surface and expansion of the area of the ice sheet cause more solar radiation to reflect back to space, promoting cooling. Changes in the mass of Antarctic ice result from the interplay of direct influences (like changes in solar radiation) and various feedback mechanisms.

ACTIVITY 17.3

Using Tide Gauge Data to Model Sea-Level Change (p. 450)

Study the section *Measuring Local Sea-Level Change Using Tide Gauges* to complete Activity 17.3.

Measuring Local Sea-Level Change Using Tide Gauges

Prior to satellite monitoring of sea-surface height, measurement of sea-level change depended on an irregular distribution of coastal and island **tide gauges** (Fig. 17.5). These data have been collected systematically in a few places since the mid-1800s, becoming more widespread and reliable throughout the 1900s. Trying to use tide-gauge records to measure global sea-level change is fraught with difficulty and uncertainty. In addition to the highly uneven distribution of tide gages, mostly located along the coastal strip of continents and a few islands, a given tide gauge might be installed on land that is rising or subsiding for some local geological reason. If the coastline where a particular tide gauge is installed is rising, for example, the average sea level determined using data from that tide gauge would indicate that local sea level is falling even if global sea level is actually constant.

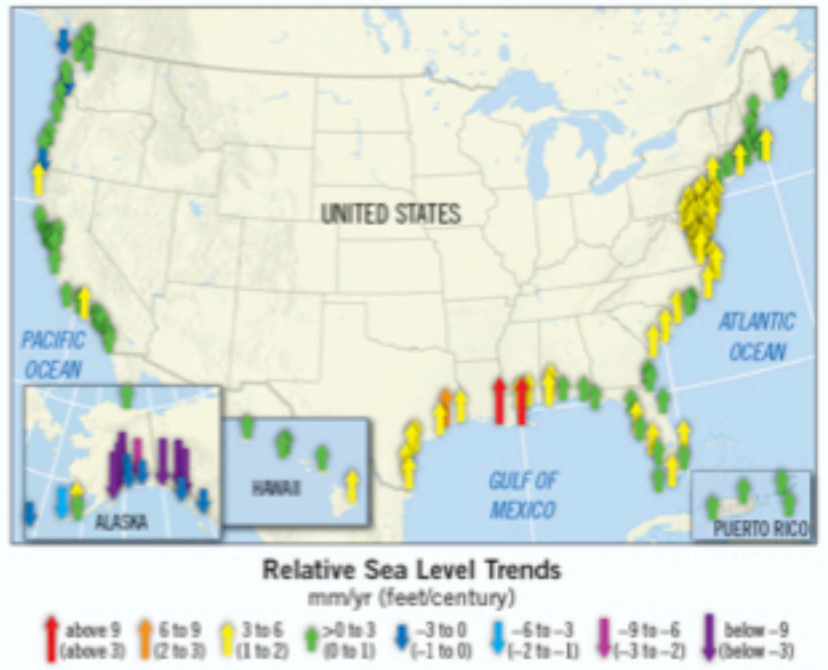


Figure 17.5 Trends in relative sea level. Relative sea level recorded locally at NOAA tide-gauge stations as of August 2018. Based on NOAA Sea Level Trends (**https://www.tidesandcurrents.noaa.gov/sltrends/sltrends.html**).

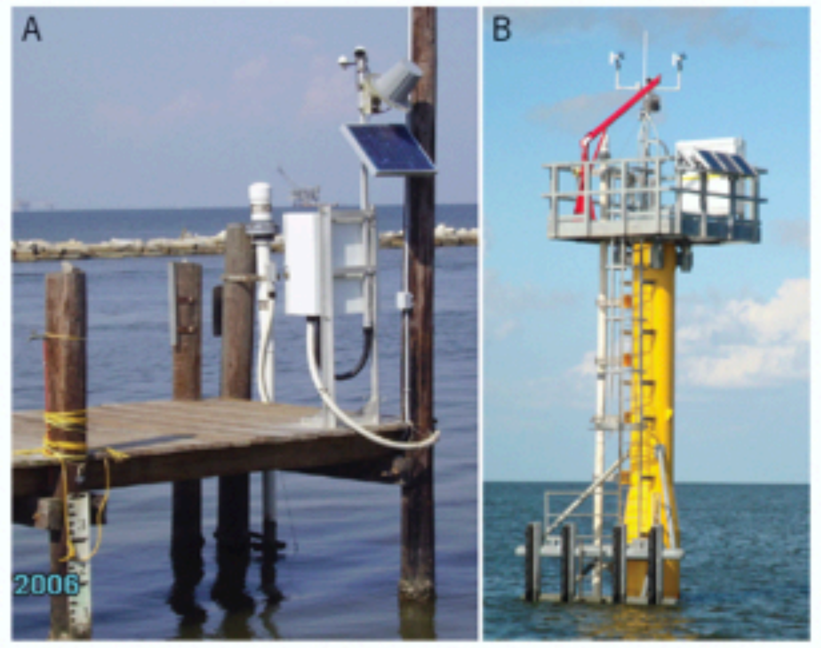


Figure 17.6 NOAA tide gauges. **A.** Tide gauge on Dauphin Island, Alabama, that uses an acoustic sensor to measure water level every six minutes. Photo: NOAA/Morgan McHugh. **B.** NOAA *Sentinel* water-level observing station along the U.S. Gulf Coast, designed to withstand category-four hurricanes.

Networks of modern tide gauges are technologically sophisticated relative to their predecessors (Fig. 17.6). In addition to making more accurate measurements that better reflect actual water-level conditions, modern tide gauges are automated so they can make many more observations every day and can transmit these data almost instantaneously using a variety of communication technologies. A tide gauge might be co-located with a fixed GPS receiver to monitor local changes in the position of the gauge as well as other sensors that collect other types of environmental data.

Glacial Isostatic Adjustment

An ice sheet is a heavy load that presses down on the lithosphere for tens of thousands of years (Fig. 17.7). Ice sheets can be up to ~4-5 km thick, which can depress the upper rock surface of the continental crust under the ice sheet by hundreds of meters below its pre-glacial level (**Fig. 17.7A**). This depression is accommodated by a flow of asthenosphere away from the area that has been loaded by ice. The elastic lithosphere bulges up around the margins of the central depression caused by the ice sheet. When the ice sheet melts and is no longer pressing down on the lithosphere, the lithosphere rebounds elastically while the asthenosphere flows back (**Fig. 17.7B**). The result is uplift where the ice once rested and subsidence of the marginal bulge. The effect is roughly the same as when a big Labrador retriever jumps up onto the sofa and depresses the cushion. Later, after he jumps off because he hears food rattling into his bowl, the cushion's upper surface slowly rises back to its original height, restoring equilibrium to the sofa.

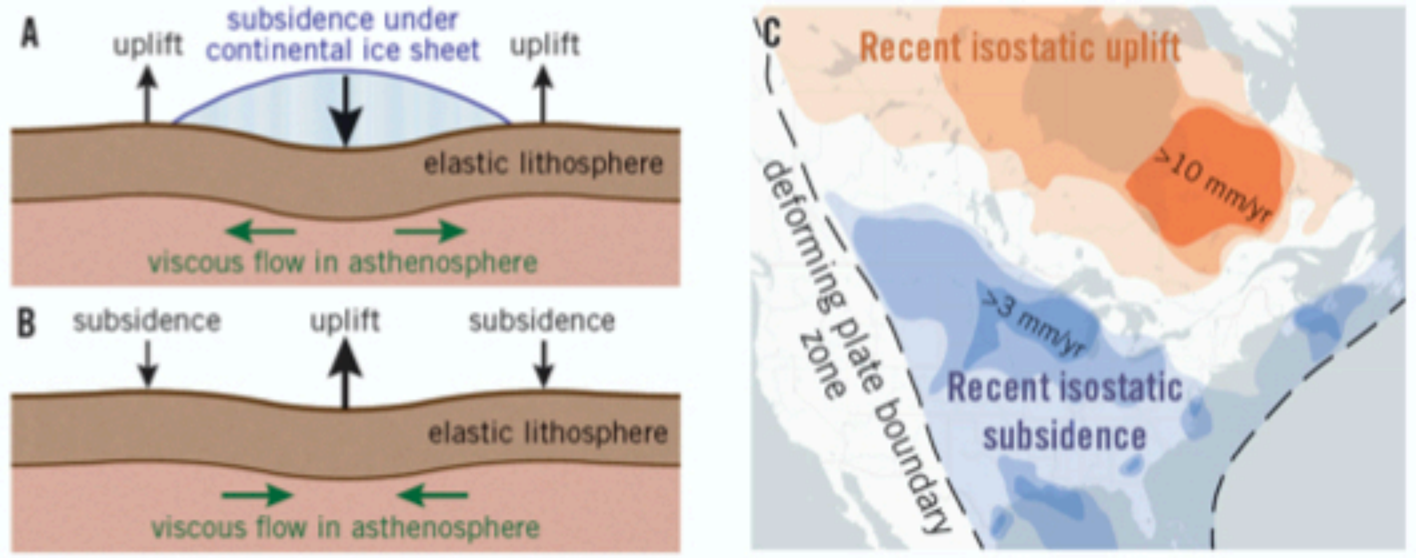
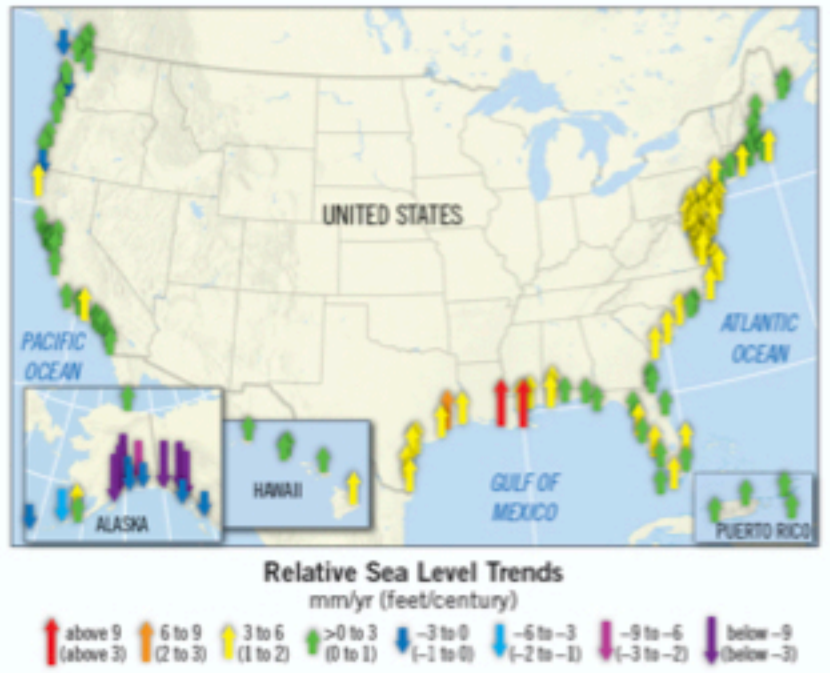


Figure 17.7 Glacial isostatic adjustment. **A.** Large ice sheets can depress the ground surface, causing an elastic bulge around the ice margin. **B.** When the ice melts, uplift occurs where the ice sheet was located and subsidence occurs along the surrounding bulge. **C.** GPS data allow us to map areas where uplift is occurring (orange) and where land is subsiding (blue), with darker colors indicating faster rates. Map C adapted from Kreemer and others (2018).



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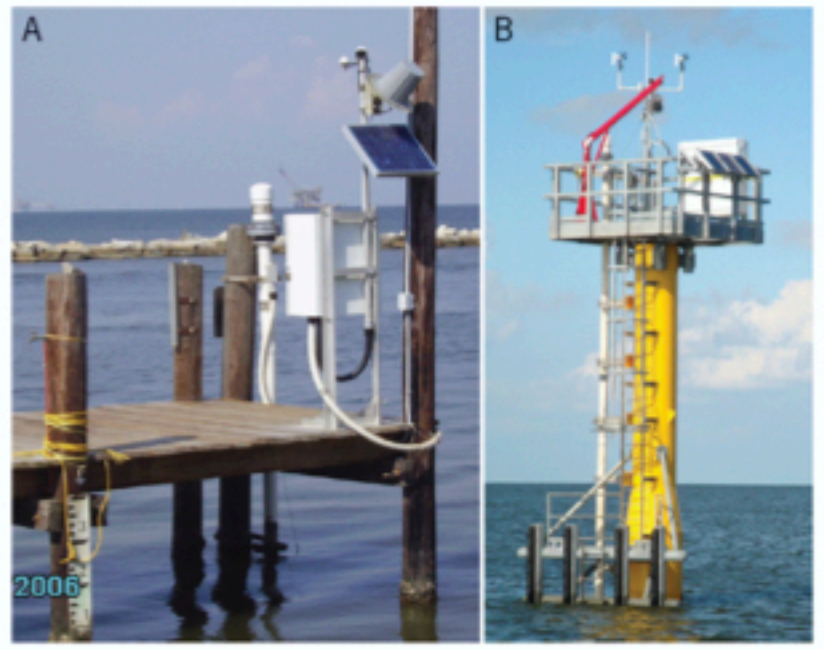

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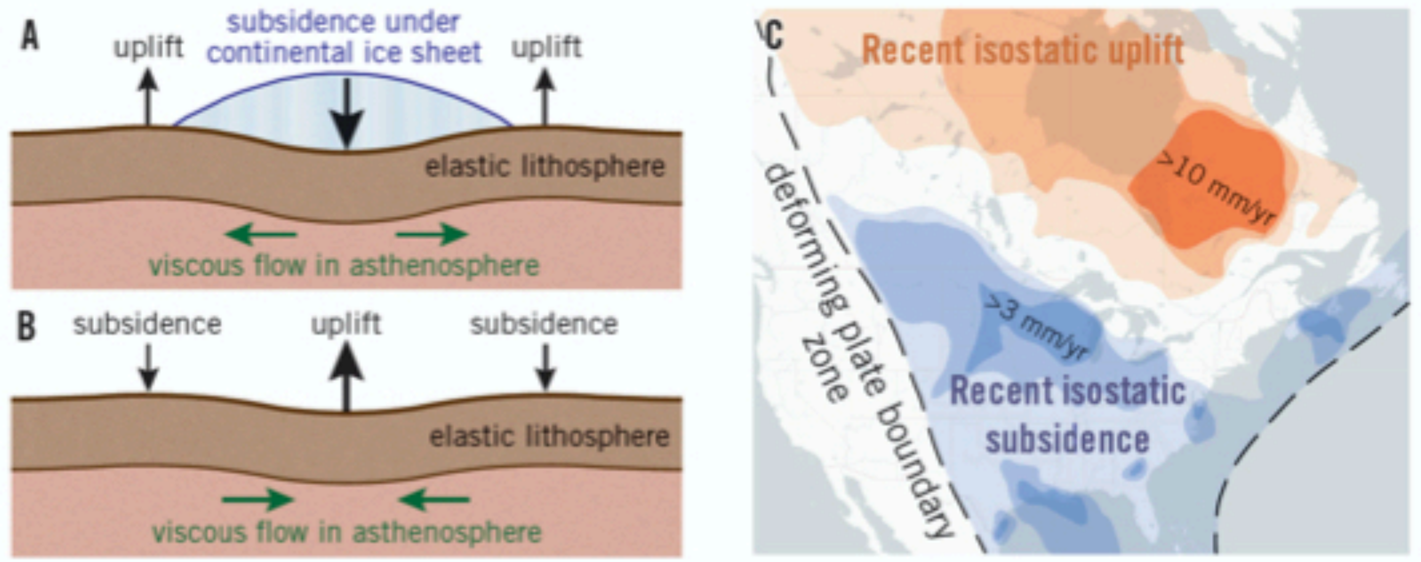

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Data from Planetary Motions, Sediment Cores, and Ice Cores

Observers across many societies have charted the motions of planets and other celestial bodies for several thousand years. The detailed observational records that are currently available, coupled with a refined understanding of gravity and celestial mechanics, allow scientists to model motions within the solar system that have an effect on the orbit of Earth around the Sun for hundreds of thousands of years. We can combine the effects of variations in the tilt of Earth's rotational axis and in Earth's orbit to define a record of how much solar radiation reaches the northern hemisphere of Earth on the longest day of the year in the north: the summer solstice. (Because continental glaciers and ice sheets can only develop on continental crust above sea level and most continental crust is in the northern hemisphere, radiation curves are typically calculated for a latitude of 65°N.) The amount of solar radiation that reaches Earth is called the **insolation**, which is measured in watts per square meter. Maximum values of insolation generally occur at the same time as **interglacials**—the warm periods between major glacial advances—throughout the Quaternary ice age of the past ~2.6 million years. Although *correlation* does not necessarily imply *causation*, there is now strong evidence that Quaternary glacial cycles have been controlled by the orbital characteristics of the Earth–Sun system.

International scientific efforts to collect ice cores in Antarctica, Greenland, and mountain glaciers in recent decades (Fig. 17.9) have resulted in compilation of an essentially continuous ice-core record dating back to 800,000 years ago. As snow accumulates each year on the surface of glaciers and ice sheets, lots of other matter suspended in the atmosphere is also deposited with the snow, including pollen, volcanic ash, soot from wildfires, blown sediment from exposed continental crust, and even lead from car exhaust. In addition to solid particles, air is trapped between the ice crystals. The snows of subsequent years compress each annual layer until it becomes dense ice, and tiny samples of ancient air are preserved in air bubbles trapped within the ice.

The layers in an ice core resemble the layers in a tree core. Like tree rings, each layer of ice corresponds to one year of mass accumulation. Scientists have solved the difficult technical problem of how to reliably sample the air, water, and other matter from datable layers within the ice, providing us with superb scientific data. Figure 17.10 is a compilation of records that are relevant to understanding variations in Earth's climate during this time period within the Quaternary ice age. Modern humans (*Homo sapiens*) appear in the geologic record less than 300,000 years ago and had a negligible effect on the global ecosystem until the widespread use of agriculture, perhaps 8000 years ago. Hence, most of the record shown in **Fig. 17.10** is free of human influence and indicates what the Quaternary has been like without us.

Here are a few background notes about the information from primary observations in **Fig. 17.10**.

- Carbon dioxide is a greenhouse gas, so higher CO_2 concentrations in the atmosphere promote warming of the atmosphere. Atmospheric CO_2 can be dissolved easily in seawater, and the efficiency of that dissolution depends on seawater temperature. Colder seawater absorbs CO_2 more efficiently than warmer seawater. Warming seawater reduces its capacity to store CO_2 and increases the transfer of CO_2 to the atmosphere.
- The exchange of gases at the atmosphere–ocean boundary illustrates the theme of *coupling* through geochemical processes. Carbon dioxide absorption by the oceans is part of the **inorganic carbon cycle** and an important *negative feedback* mechanism that regulates climate. Note that phytoplankton also stores CO_2, through photosynthesis, which is transferred to the ocean store through the **organic carbon cycle**.
- Methane is also a greenhouse gas and is also soluble in seawater, so the same relationships noted for CO_2 are true of CH_4. Warming seawater can lead to the release of methane from methane hydrates near the seafloor,

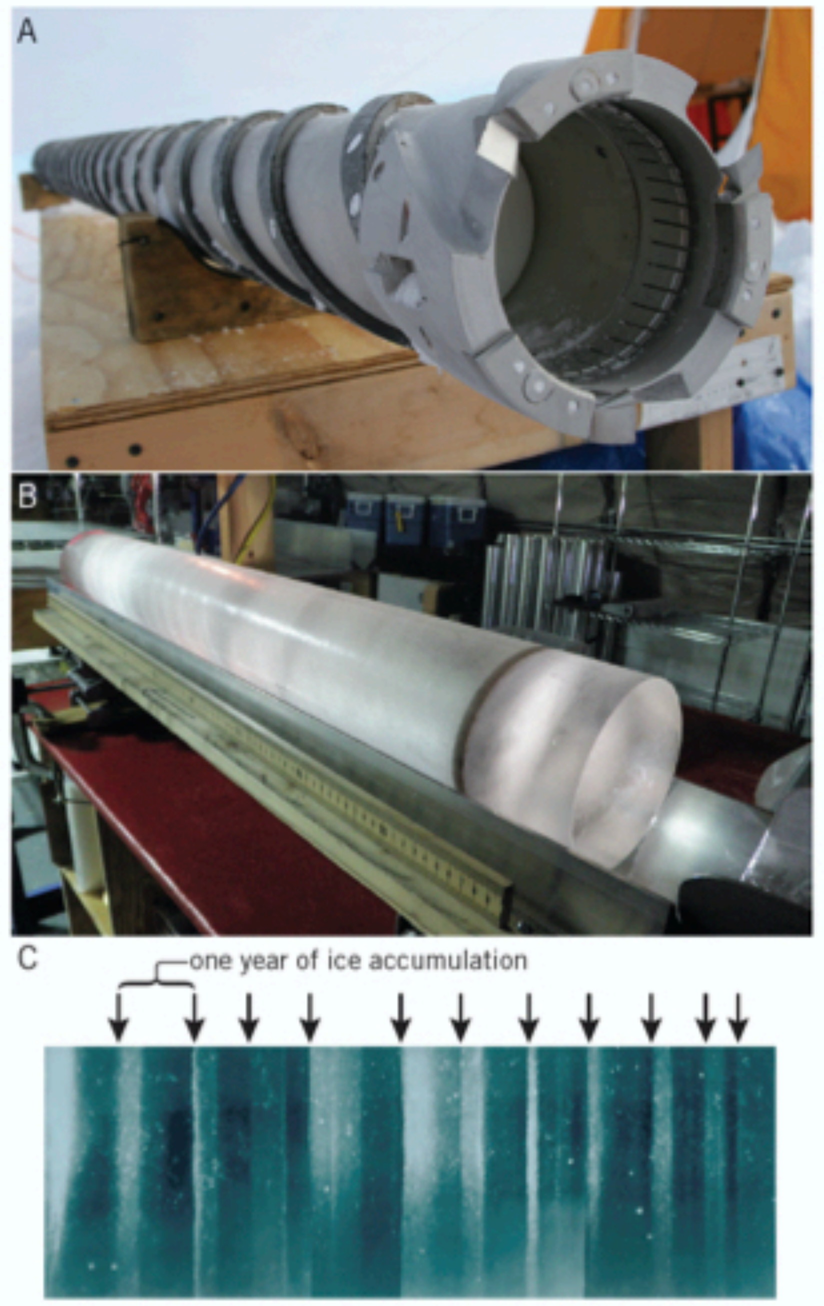

Figure 17.9 Ice core. **A.** Core barrel and bit used to collect ice cores in Antarctica. **B.** Ice core from the West Antarctic Ice Sheet Divide, showing a layer of ash (dark band near the closer end of the core) preserved in the ice from a volcanic eruption ~21,000 years ago. **C.** Short (19 cm) section the GISP2 ice core from Greenland showing annual layers with lighter summer layers sandwiched between darker winter layers. Photos: Steven Profaizer, Heidi Roop, and Anthony Gow, National Science Foundation.

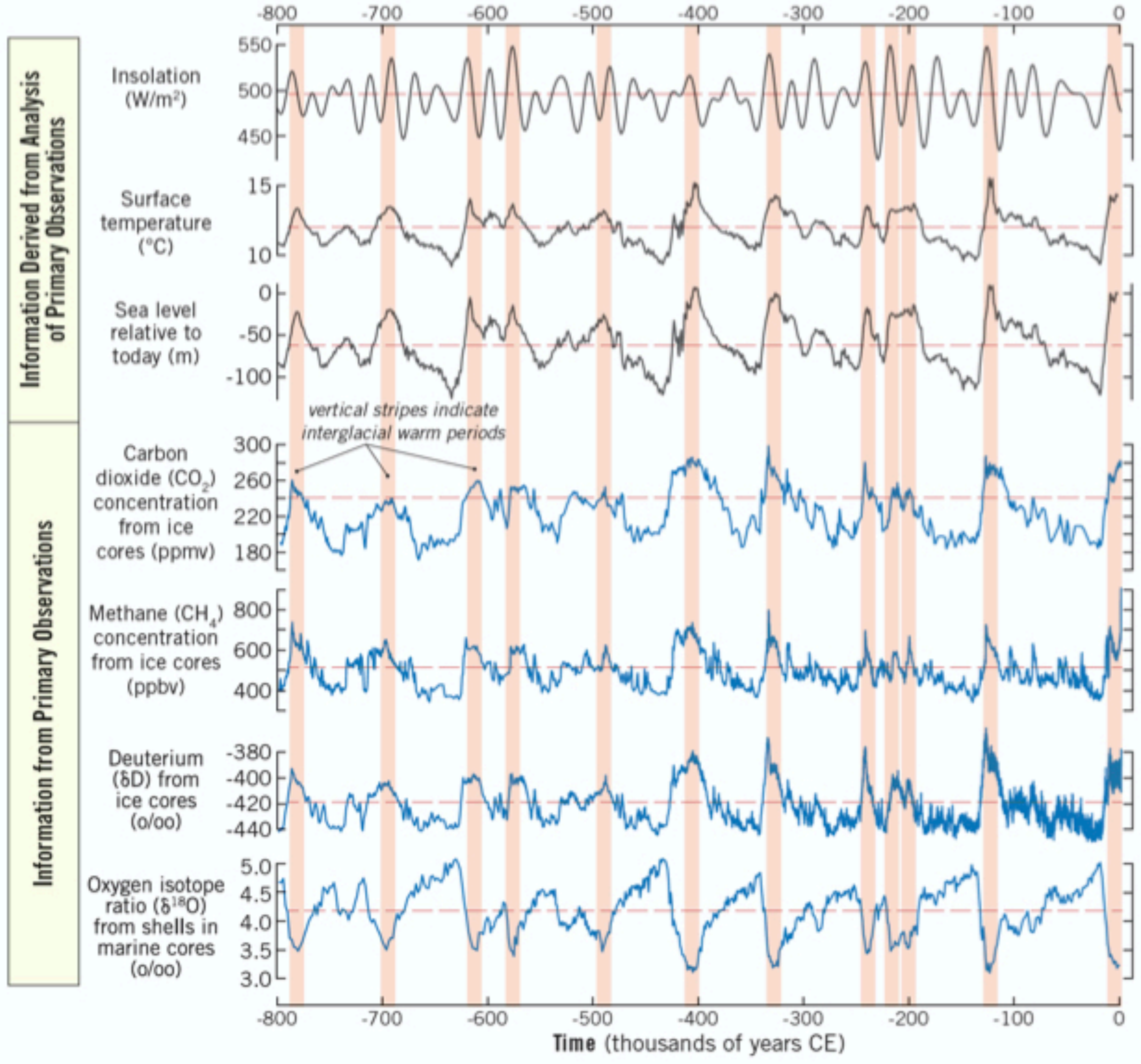

Figure 17.10 800,000 years of climate record. Time-series graphs of peer-reviewed published data relevant to the study of climate change over the past 800,000 years.

and warming atmosphere can cause release of methane from areas previously covered in permafrost. Both of these major carbon sinks are affected by ***positive feedback***, causing instability where a rise in temperature results in the release of methane that, in turn, causes temperature to rise even more.

- All hydrogen atoms have 1 proton, and most do not have any neutrons, so the most common stable isotope of hydrogen is ^1H with an atomic mass of 1. We'll refer to ^1H as *normal hydrogen*. **Deuterium** (^2H) is another stable isotope of hydrogen containing one neutron along with its one proton (atomic mass = 2), so deuterium is considered a "heavy" isotope relative to normal hydrogen. To shorten a long story, deuterium is less abundant in water that precipitates as snow when the atmosphere is colder. This is simply because, with less available heat energy, the process of evaporation favors isotopically lighter atoms. We use a derived value (δD) to describe the abundance of deuterium in a water sample compared with its abundance in typical seawater (standard mean ocean water or SMOW). Smaller (more negative) δD values in **Fig. 17.10** are interpreted to indicate colder atmospheric temperature.
- All oxygen atoms have 8 protons and most have 8 neutrons, so the most common stable isotope of oxygen is ^{16}O with an atomic mass of 16. Another stable isotope of oxygen, ^{18}O, contains 10 neutrons (atomic mass = 18) and might be called "heavy" oxygen. Marine organisms that form calcium carbonate ($CaCO_3$) shells incorporate oxygen derived from seawater. To shorten another long story, ^{18}O is more abundant in seawater during ice ages, and that variation is reflected in the $\delta^{18}O$ in carbonate shells formed during ice ages. Larger $\delta^{18}O$ values in **Fig. 17.10** are interpreted to indicate increased continental ice mass and colder atmospheric temperature.

The quantities δD and $\delta^{18}O$ are expressed as ratios: as parts per thousand or "per mille." The symbol $^o/_{oo}$ is used for the ratio 1/1000, just as the symbol % is used for the ratio 1/100. For example, if a bowl filled with 1000 nuts had just 3 peanuts, the peanut composition in the bowl would be $3^o/_{oo}$ or 3 per-mille.

Some Consequences of a Warming Climate

It would take far more space than we can devote to this subject to list and explain the significant consequences of a warming climate. Here, we briefly mention a small selection of results that are relevant to Earth's ecosystem, human society, and the geologic record. We present this material with the understanding that we all share a responsibility to consult reliable sources of information and become better informed about the challenges we face together as a result of a warming climate. We are not powerless to affect positive change with respect to the part of climate change that is attributable to human activities—actions that are likely to have a strongly beneficial impact on generations of people yet unborn.

Effects on the Biosphere

An estimated 40% of the CO_2 emitted by humans stays in the atmosphere, while about half of the remainder is taken up on land by plants and soils. (In fact, the fastest process for removing CO_2 from the lower atmosphere is photosynthesis.) The rest is absorbed by the world's oceans. The CO_2 reacts with seawater to produce carbonic acid (H_2CO_3). It has been estimated that the acidity of the world's oceans has increased by about 30% since the industrial revolution, reaching levels today that are higher than at any time in the previous 55–60 million years. This process also depletes carbonate ions, which are essential for organisms to build carbonate shells and skeletons. **Ocean acidification** caused by increasing atmospheric concentrations of CO_2 poses a significant threat to the entire ocean ecosystem.

For example, plankton like the pteropods shown in Fig. 17.11 form the base of the oceanic food chain for many larger marine animals. A healthy pteropod has a thin smooth shell that is strong enough to support the organism as it swims along through normal seawater (**Fig. 17.11A**). When exposed to seawater that is more acidic than normal, the shell begins to dissolve (**Fig. 17.11B**). Yet-higher acidity further compromises the shell and makes it difficult for the organism to develop or function normally (**Fig. 17.11C**). This effect has been observed in organisms collected just offshore from Washington to northern California and has been reproduced in the laboratory. In addition to dissolution of existing shells, new organisms trying to grow in a more acidic environment experience difficulty developing their shells because of the depleted supply of carbonate ions in the seawater.

The *Argo* floats have documented a warming ocean system. An estimated 90% of the energy from warming of the Earth system has been stored in the oceans, and this warming, along with rapidly increasing acidification, is among the more important environmental stressors, producing a negative impact on corals and many other ecological communities in the world's oceans. A warming ocean transfers more of its dissolved load of CO_2 to the atmosphere, causing additional warming while reducing the uptake of oxygen to seawater. Reduction in oxygen availability in the oceans (**ocean deoxygenation**) is yet another important change in seawater chemistry that impacts marine ecosystems.

Research on biological adaptations to change in the modern environment can help geoscientists interpret the fossil record with respect to responses to ancient climate (paleoclimate) change. For example, paleobotanists have documented variations in leaf shape over time that can be interpreted as manifestations of changing temperature (Fig. 17.12). Plants whose leaf margins feature teeth or serrations are more

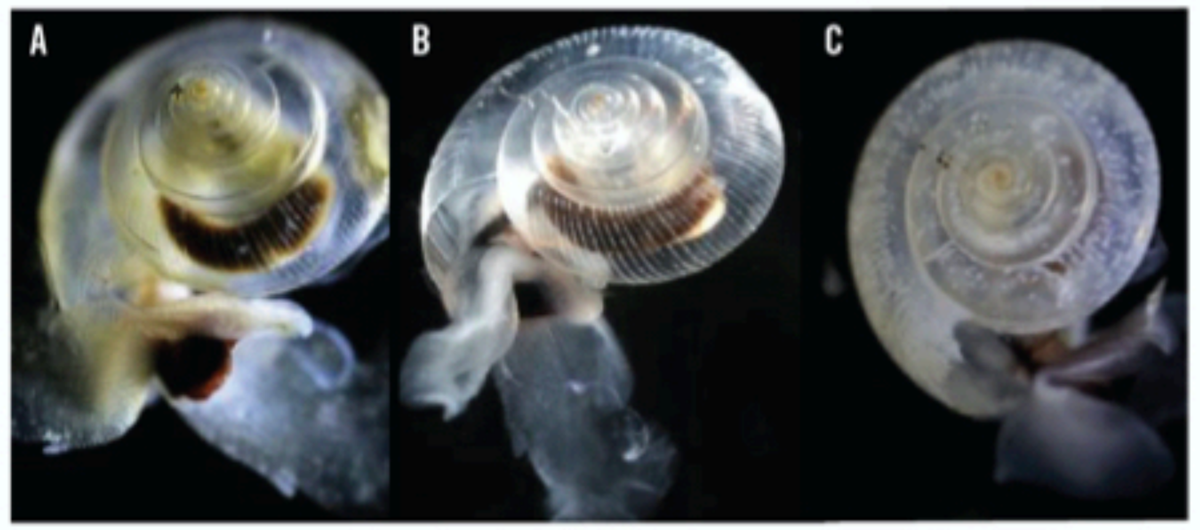

Figure 17.11 Pteropod (plankton) shell dissolution due to ocean acidification. Pteropods collected along the west coast of the United States during an offshore survey in 2011. **A.** Healthy pteropod with well-formed shell, indicating locally normal marine conditions. **B.** Pteropod displaying evidence of shell dissolution due to ocean acidification. **C.** Pteropod with extensive damage to shell due to increased acidity. Photos: Nina Bednarsek.

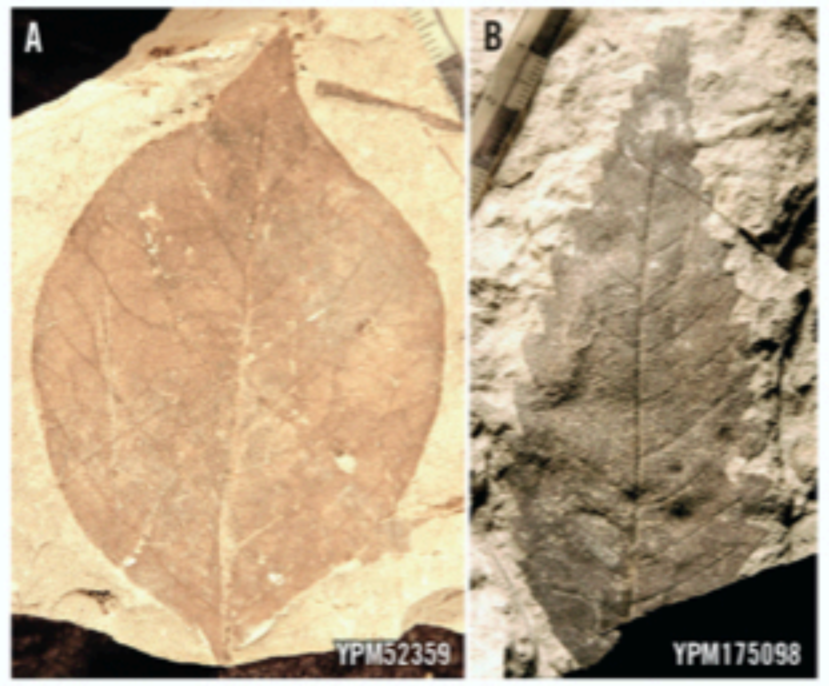

Figure 17.12 Fossil leaves as temperature indicators. A. Fossil leaf with smooth (entire) margin—more common in warmer climates. B. Fossil leaf with toothed (serrated) margin, which is more common in cooler climates. Photos: Dan Peppe, Baylor University, of specimens from Yale Peabody Museum.

prevalent in cooler climates with shorter growing seasons. The teeth are an adaptation that allows plants to begin photosynthesis a little bit earlier in the spring. In contrast, smooth leaf margins do not lose water vapor as easily as serrated leaf margins, so smooth-leafed plants are more prevalent in warmer climates with longer growing seasons.

A rapidly changing environment might be difficult or impossible for some species to survive. Environmental change is particularly challenging for species that are highly adapted to a specific habitat. Polar bears, for example, are highly adapted to life on or around sea ice (Fig. 17.13). The bears roam widely across the sea ice to hunt their primary

Figure 17.13 Warming Arctic conditions affect habitats. Adult mother polar bear and her cubs on Arctic sea ice north of the Alaska coast. Reduction in summer sea ice in the Arctic constricts the natural habitat of species like the polar bear. Habitat constriction, fragmentation, or destruction can result in extinction. Photo: Mike Lockhart, USGS.

food source—seals—which provides the high-fat diet that they need. The Arctic is warming faster than most other parts of Earth, resulting in a steady reduction in arctic sea ice over time and a shrinking of polar bear habitat.

Effects on Society

The table of contents of this laboratory manual is a partial roadmap through important topics affected by a rapidly increasing human population in a warming world that is likely to be characterized by more frequent and more intense weather events. Access to mineral resources in an industrial society is always challenging, but the need for expanded use of batteries to store electric power will require significant amounts of nickel, lithium, various rare-earth elements, cadmium, cobalt, manganese, and other elements. Devices for harnessing wind, water, and solar energy can also require scarce mineral resources.

Adequate accessible supplies of potable water are affected by local increases in aridity including increased evaporation from reservoirs, saltwater intrusion to groundwater aquifers in coastal areas affected by sea-level rise, groundwater mining to meet the immediate needs of a growing population, and reductions in snowpack and glaciers in mountainous regions. River systems are expected to be subject to more frequent and extreme flooding conditions. Some areas will be subject to desertification. In addition to polar regions where the effects of climate change are most pronounced, coastal areas likely to be most strongly impacted by the effects of a warming climate as the temperature, acidity, and level of the oceans increase over time.

Knowledge of these problems empowers us to seek solutions and mitigation strategies that can be implemented now and over the coming decades. The challenge is to find a good mix of solutions to global problems that meet the legitimate needs of all of us.

ACTIVITY 17.6

Local Effects of Sea-Level Rise (p. 459)

Study the sections *Sea-Level Rise* and *Exposure to Sea-Level Rise in the United States* to complete Activity 17.6.

Sea-Level Rise. The rate of global mean sea-level (GMSL) rise as of mid-2019 was ~3.3 mm/yr, and that rate has been increasing. According to the *Fourth National Climate Assessment* (2018), GMSL is likely to rise by at least 0.3–1.3 m (1-4 ft) by the year 2100, and a rise of 2.5 m (8 ft) by 2100 is physically plausible. GMSL will continue to rise for centuries to come, so the year 2100 is not a finish line beyond which we need not be concerned.

The last time Earth's mean surface temperature was as high as today was about 125,000 years ago when sea level was 6–9 m (20–30 ft) higher than today. The last time the atmospheric concentration of CO_2 was as high as today was about 3 million years ago when sea level was about 20 ± 10 m (66 ± 33 ft) higher than today.

Today, approximately 600 million people worldwide live in coastal regions within 10 m of sea level. By 2050, this figure is expected to grow to 1 billion, or nearly 10% of the projected global population. Coastal populations face threats from sea-level rise and face the risk of displacement over two different time scales. ***Long-term sea-level rise*** can result in the gradual inundation and loss of parts of the coast affecting the population, infrastructure, beaches, cliffs, and coastal ecosystems such as wetlands and marshes. The extent of submergence can be mapped and quantified. For example, along the Atlantic Coast during the decade between 2001 and 2011, approximately 34 km^2 (13 mi^2) of coast were lost to the sea—tidal and non-tidal wetlands as well as dry land.

Over ***shorter time scales***, the gradual rise in sea level can amplify the inland extent of flooding from seasonal storm events (Fig. 17.14). Storms pose a serious hazard because coastal waters can rise by several meters (or more) due to the combined effects of coastal processes. If a storm surge occurs during a high tide and periods of elevated local river discharge, then large volumes of water pile up along the shore. During severe storms, strong onshore winds can drive up water levels by several meters. Adapting to the threat of both long- and short-term coastal hazards is expensive, with some estimates of annual costs worldwide reaching $1 trillion by the year 2100.

Exposure to Sea-Level Rise in the United States. Almost 40% of the population of the United States live in areas affected by coastal processes. Although the coasts of the continental United States are home to cities with the largest collective populations, the country actually includes widely distributed territories from the U.S.

Figure 17.14 Inundation of coastal areas. Flooding in New Iberia, Louisiana, after Hurricane Ike in September 2008. New Iberia has an elevation of about 6 m above mean sea level. Photo: U.S. Coast Guard.

Virgin Islands and Puerto Rico to the Northern Mariana Islands, Guam, and American Samoa. Islands are particularly exposed to tropical cyclones and rising sea level, to the extent that some low-lying islands are likely to become uninhabitable if not completely submerged in the future.

The west coast of the continental United States is characterized by significant elevation changes (high topographic relief) dominated by sea cliffs in many locations due to past tectonic activity along the plate margin. In these areas, topography and resistant rock provide a buffer against a rising sea level. However, large populations in California and Oregon live in low-lying coastal areas, including bays and estuaries, close to present-day sea level. These areas are particularly exposed to the effects of sea-level rise and major storms.

Using San Francisco Bay as an example, 100-year storm events could elevate water levels by an average 1.8 m ± 0.8 m above the maximum sea level and pose a significant threat to people and wildlife. These values do not include the potential effects of high river discharges and El Niño events that would increase the flood level. Along parts of the coast, storm waves can be as large as 4.0 m ± 2.8 m. (Outside of the San Francisco Bay area along Pacific-facing beaches, waves as high as 10–15 m can occur.) Now add the effect of rising global mean sea level and more frequent and extreme storm events due to a warming ocean and we have a set of difficult challenges to address. The potential cost in property damage is on the order of tens of billions of dollars.

In order to develop effective mitigation strategies for these threats, scientists are constructing sophisticated models integrating ***global-scale data*** of future wind patterns with ***regional-scale models*** of waves and tides and applying them to 3-D models of coastal bathymetry and topography. By combining projections of background sea-level rise and extreme storm events, scientists can provide tools for land-use planners and governments to help them mitigate some of the risk involved in developing coastal areas.

The eastern United States is not affected by recent tectonic activity, but its coastal topography reflects ancient tectonic events. Several hundred million years ago, the African and Eurasian plates collided with eastern North America to produce the Appalachian Mountains, before drifting apart with the opening of the north Atlantic Ocean Basin around 200 Myr ago. Parts of the coastline in New England intersect this old Appalachian Mountain trend and have significant topographic relief along the rocky coast. In the middle and southern parts of the coastline, generally south of New York, a low-lying coastal plane provides relatively little relief. This area is particularly exposed to the effects of major storms and the steady rise of sea level.

Although not affected by active tectonics, the east coast is subject to vertical crustal motions associated with glacial isostatic adjustments (GIA) related to the melting of the Laurentide ice sheet, which melted completely about 6000 years ago (Fig. 17.7). These slow vertical motions of the crust are measured using data from networks of GPS/GNSS stations such as the Network of the Americas (**https://www.unavco.org/projects/major-projects/nota/nota.html**) that share data worldwide. The crust from southern Connecticut to Florida and along the Gulf of Mexico coast is subsiding at various rates. To the north, GIA is an important contributor to subsidence, whereas farther south, local subsidence might be due to pumping of hydrocarbons, groundwater withdrawal, compaction of coastal sediments, or a combination of causes. The Chesapeake Bay region and gulf coast experience particularly high rates of subsidence. High local subsidence of the crust along a coast is reflected in the locally high rate of relative sea-level change measured using tide gauges over many years. Isostatically driven subsidence amplifies the local effects of global mean sea-level rise for centuries to come.

Local sea level changes over time spans of many years along coasts that are undergoing uplift or subsidence. When global sea level remains constant, local sea level *increases* where coastal subsidence occurs and *decreases* where coastal uplift occurs. The effects of global sea level rise are added to these local effects—local sea level rise is more severe along a subsiding coastline and less severe along a coastline that is undergoing uplift. Virtually all of these local sea level changes are related to climate change, human activities, or both.

NASA is particularly concerned with sea-level rise because two thirds of its constructed infrastructure (buildings, launch facilities) is located within 5 m (16 ft) of sea level (**https://sealevel.nasa.gov/understanding-sea-level/key-indicators/global-mean-sea-level**). Additional, reliable information about climate change is available for free online from the U.S. Global Change Research Program in the Fourth National Climate Assessment: volume 1 (**https://science2017.globalchange.gov**) and volume 2 (**https://nca2018.globalchange.gov**).

Mastering Geology™

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How Does Rising Temperature Affect Sea Level?

Activity 17.1

Name: ______________ Course/Section: ______________ Date: ______________

Learning GOAL You will use observations from an experiment, orbital satellites, and floating robotic sensors to develop a basic understanding of how increasing the temperature of water can change its volume and hence the level of its upper surface in a container (or in an ocean basin).

A What happens to the volume of liquid water when its temperature is raised? To answer this question, either perform the following simple experiment or watch the brief video available at **https://qrgo.page.link/Hd51t**

Figure A17.1.1

You need the following items for the experiment (Fig. A17.1.1): a small glass Erlenmeyer flask, a two-hole rubber stopper sized for the top of the flask, a digital or alcohol thermometer that can be inserted through a hole in the stopper, a glass tube that can be inserted through the other hole in the stopper, a heat source such as a hotplate or a heat lamp, cold tap water (fresh water), and food coloring.

Step 1. Fill the flask to the top with cold water mixed with food coloring so you can easily see the water level.

Step 2. Carefully insert the thermometer and glass tube through the holes in the stopper and place the stopper assembly in the top of the flask. The stopper will displace some water at the top of the flask, and some of that displaced water should move up into the glass tube. If you can't see water in the tube, add drops of water until the water level is visible above the stopper in the tube.

Step 3. Before heating the assembly, mark the initial water level in the tube.

Step 4. Apply heat to the bottom of the flask either by setting the flask on a hotplate or by pointing the heat lamp toward the base of the flask.

Step 5. After a few minutes of heating, observe whether heating causes a change in water volume by seeing whether the water in the tube rises, falls, or remains at a constant level.

Based on your observations, write a brief statement in the space provided that describes the effect (if any) of an increase in water temperature on the liquid volume of fresh water.

Climate Indicators, Today and for the Past 800,000 Years

Technological advances have greatly enhanced our ability to make accurate observations, share and analyze data, and communicate widely about scientific ideas. Climate science has advanced because of the extraordinary data-collection efforts of astronomers, glaciologists, oceanographers, atmospheric chemists, and engineers working behind the scenes and creating technology that can achieve ambitious scientific objectives, often in very challenging environments.

ACTIVITY 17.4

Carbon Dioxide in the Atmosphere (p. 453)

Study the section *The Keeling Record from Mauna Loa Observatory* to complete Activity 17.4.

The Keeling Record from Mauna Loa Observatory

A new observatory was dedicated in June 1956 on the north slope of the Mauna Loa Volcano on the island of Hawai'i. Initially built as a U.S. Weather Bureau station, the **Mauna Loa Observatory (MLO)** is almost 3400 ft above sea level and about 2500 ft below the volcano summit. MLO is far away from continental sources of air pollution, is above the atmospheric inversion layer below which local air pollution is typically concentrated, and is an excellent site from which to sample pristine air from the center of the Pacific Ocean (Fig. 17.8). Dave Keeling, who was an atmospheric geochemist working for Scripps Institution of Oceanography, established a CO_2 monitoring program at MLO and analyzed his first atmospheric sample there in early 1958. That scientific effort continues to this day and is the world's oldest atmospheric CO_2 monitoring program.

The effects of volcanic activity that might be a source of air sample contamination are carefully monitored and removed from the final data obtained at MLO. Over decades, different methods have been used to collect and analyze the air samples, but the data quality has always been exceptionally high. The MLO is now a part of NOAA's Earth System Research Laboratory (**https://www.esrl.noaa.gov/gmd/obop/mlo/**). NOAA and Scripps independently analyze samples of air collected at MLO (**https://scripps.ucsd.edu/programs/keelingcurve/**).

The **Keeling curve** showing the atmospheric concentration of CO_2 measured at MLO from March 1958 to March 2019 is included in Activity 17.4 as **Fig. A17.4.2**. In order to interpret the fine structure of the multi-year curve, it helps to consider two relevant facts. First, photosynthetic plants capture CO_2 for use in synthesizing carbohydrate molecules to store chemical energy. Trees capture CO_2 and store or sequester it through the production of new wood. Thus, plants can act as CO_2 sinks. Second, photosynthesis and tree growth tend to be seasonal, so the effectiveness of living plants in absorbing CO_2 also tends to be seasonal. Similarly, the emission of CO_2 by soils and decaying organic material—acting as CO_2 sources—is also seasonal. Dave Keeling unlocked this mystery of the annual fluctuation in CO_2 concentration by March 1960.

In March 1958, Dave Keeling measured an atmospheric CO_2 concentration of 313 parts per million (ppm) at MLO. The monthly average for May 2019, just over 61 years after that first measurement, was 414.8 ppm—more than 100 ppm higher! Our best current data indicates that the atmospheric concentration of CO_2 has not been as high as it is now since about 3 million years ago.

ACTIVITY 17.5

The Climate Record from Cores (p. 456)

Study the section *Data from Planetary Motions, Sediment Cores, and Ice Cores* and review the prior sections on climate indicators to complete Activity 17.5.

Climate Indicators, Today and for the Past 800,000 Years

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Name: ______________________ Course/Section: ______________ Date: __________

Learning GOAL You will become familiar with the record of atmospheric carbon dioxide (CO_2) as measured since 1958 at the Mauna Loa Observatory as well as a longer record from an ice core that extends back about 2000 years and explore the trends evident in these data. How does CO_2 concentration in the atmosphere seem to correlate (if at all) with Earth's surface temperature?

A What is the most recently measured concentration of atmospheric CO_2 at the Mauna Loa Observatory? On the web, navigate to **https://scripps.ucsd.edu/programs/keelingcurve/** to find the latest reading, which is expressed in units of parts per million.

date of latest reading: ______________ CO_2 concentration: __________ ppm

B Figure A17.4.1 shows a two-year record of atmospheric CO_2 measurements at Mauna Loa Observatory.

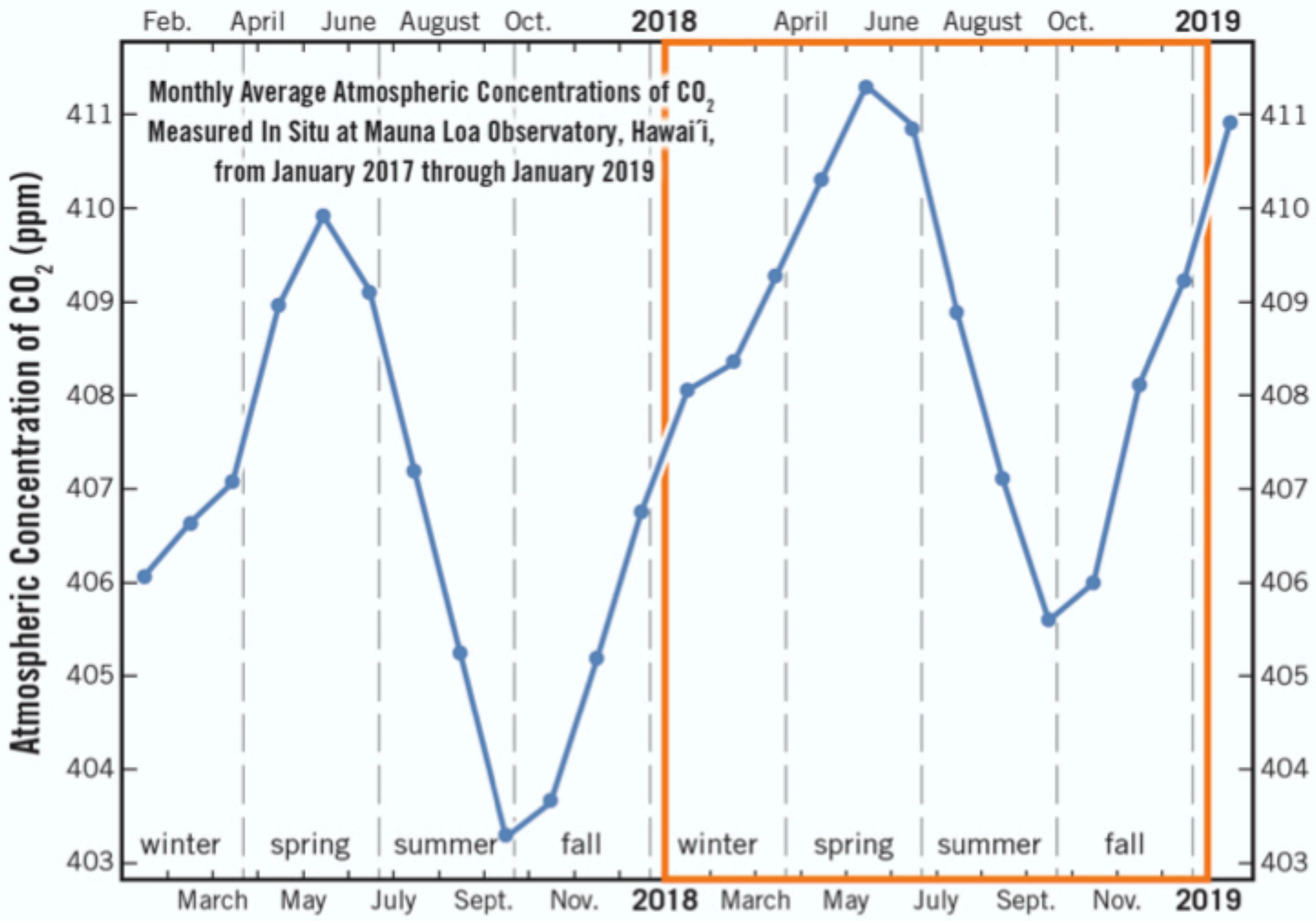
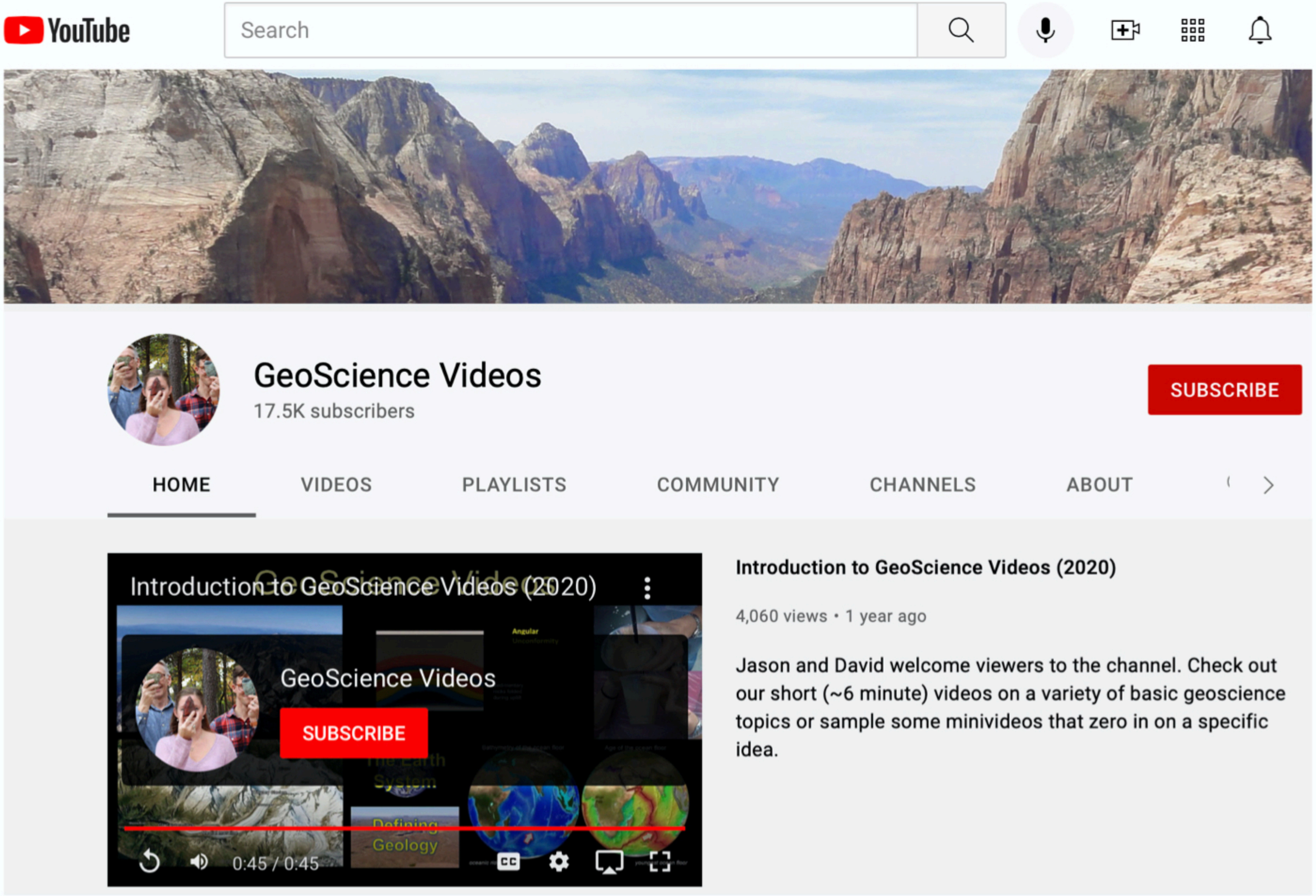


Figure A17.4.1

1. In what season of the year (spring, summer, fall, winter) is the CO_2 concentration at its greatest? ______________ . . . least? ______________

2. Form a hypothesis that might explain the observations you just made about the seasonal variation of atmospheric CO_2 and write a brief description in the space provided. *Hint*: Plant photosynthesis reduces the CO_2 concentration and decay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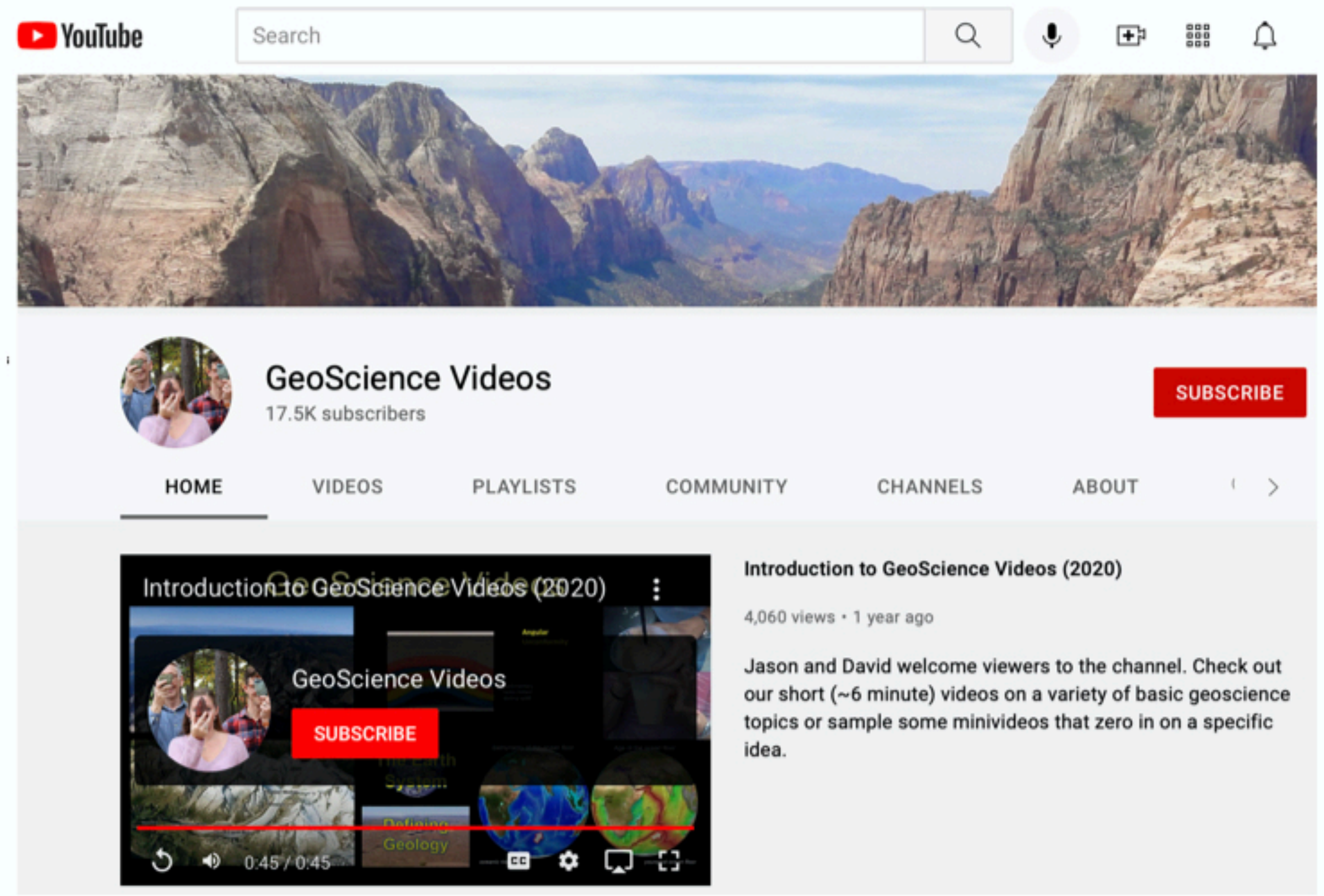
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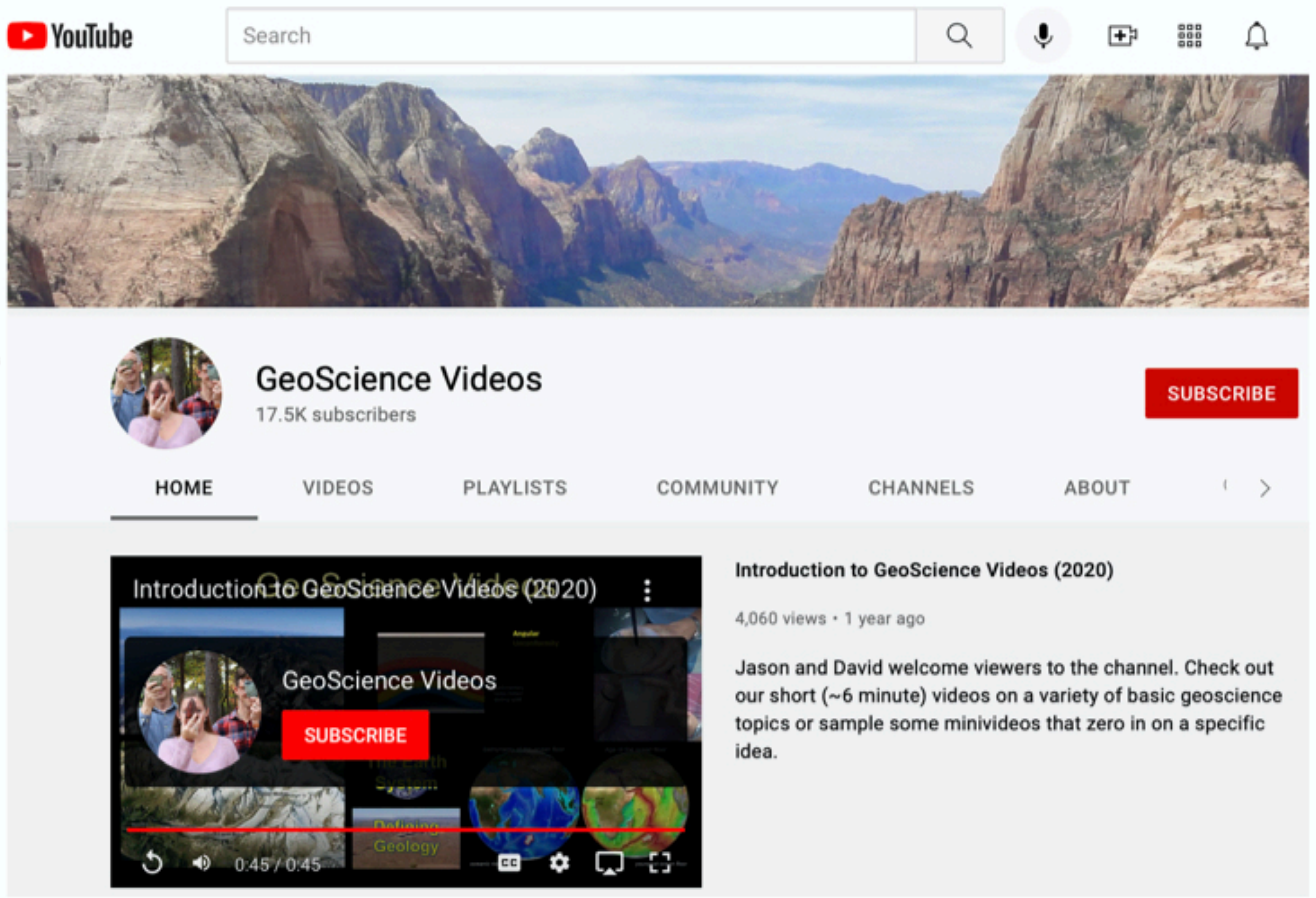

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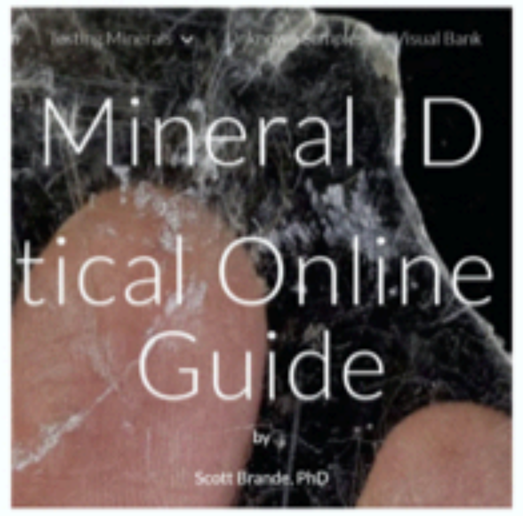
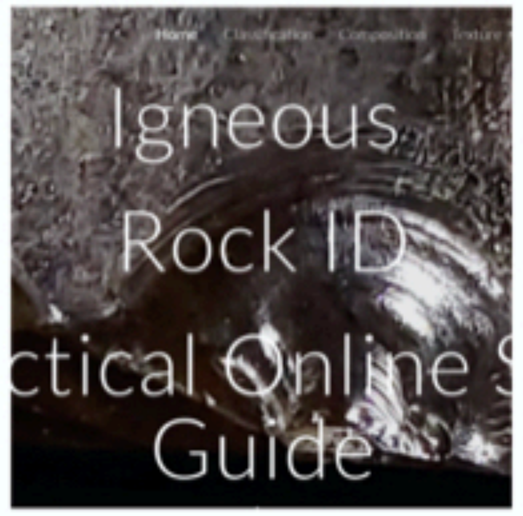
If you're looking for online resources for **mineral** and **rock identification**, look no further. In various stages of development. ***Distribute these links to students and colleagues.***



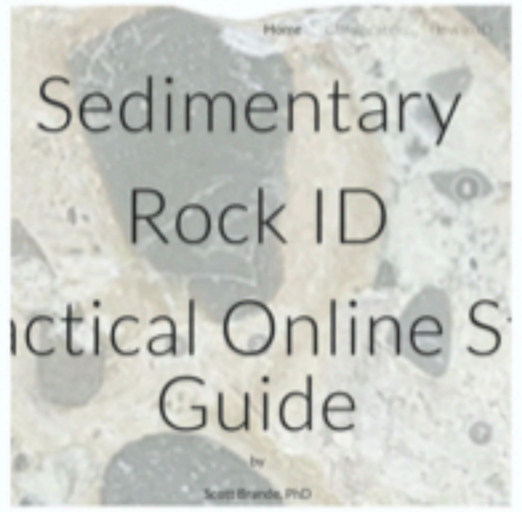
Minerals

omg.georockme.com



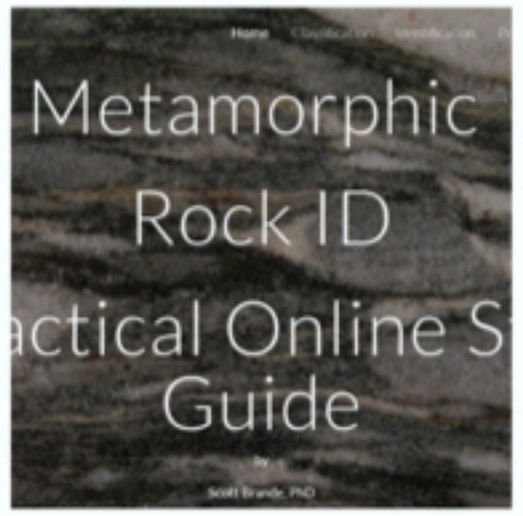
Igneous Rock

igg.georockme.com



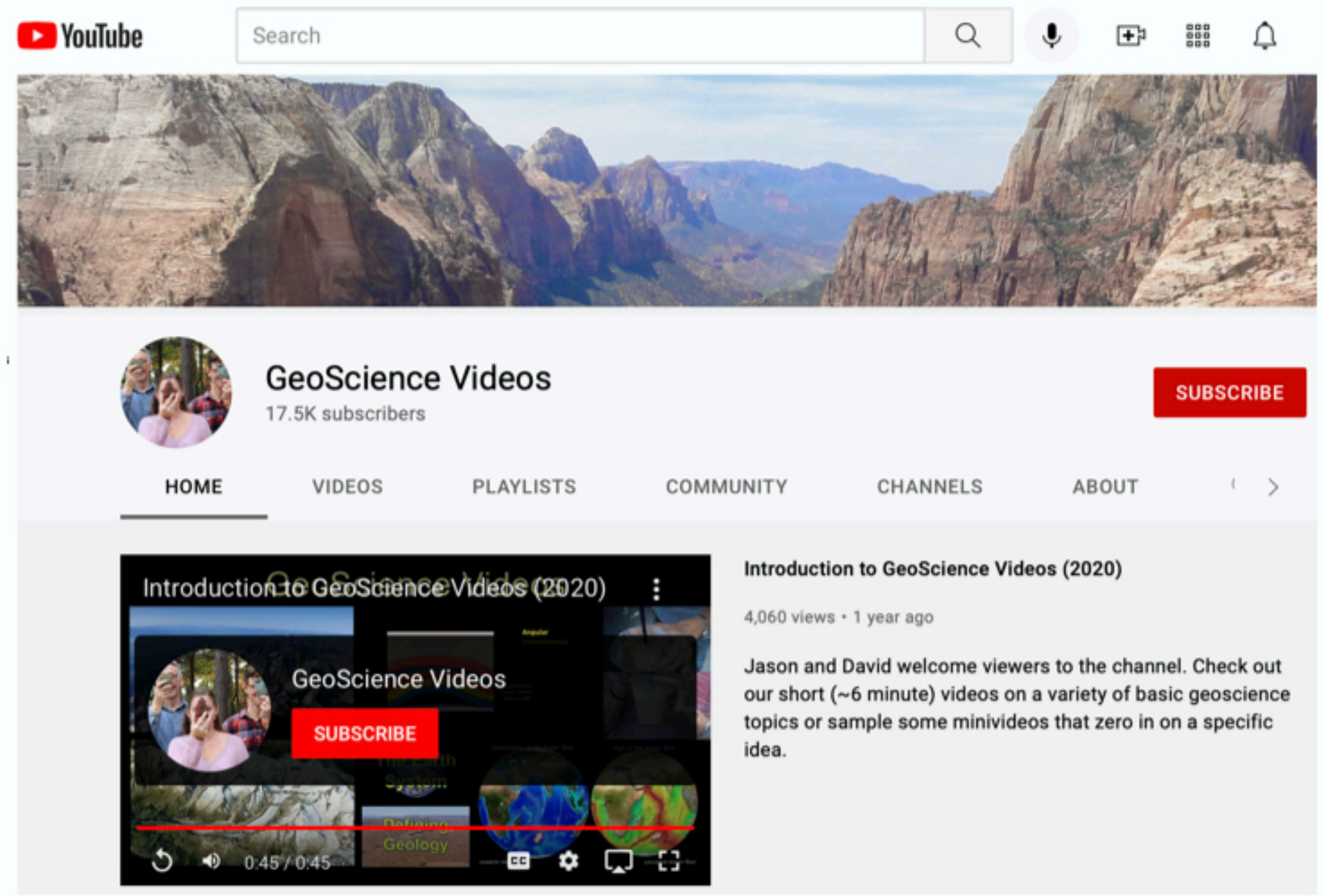
Sedimentary Rock

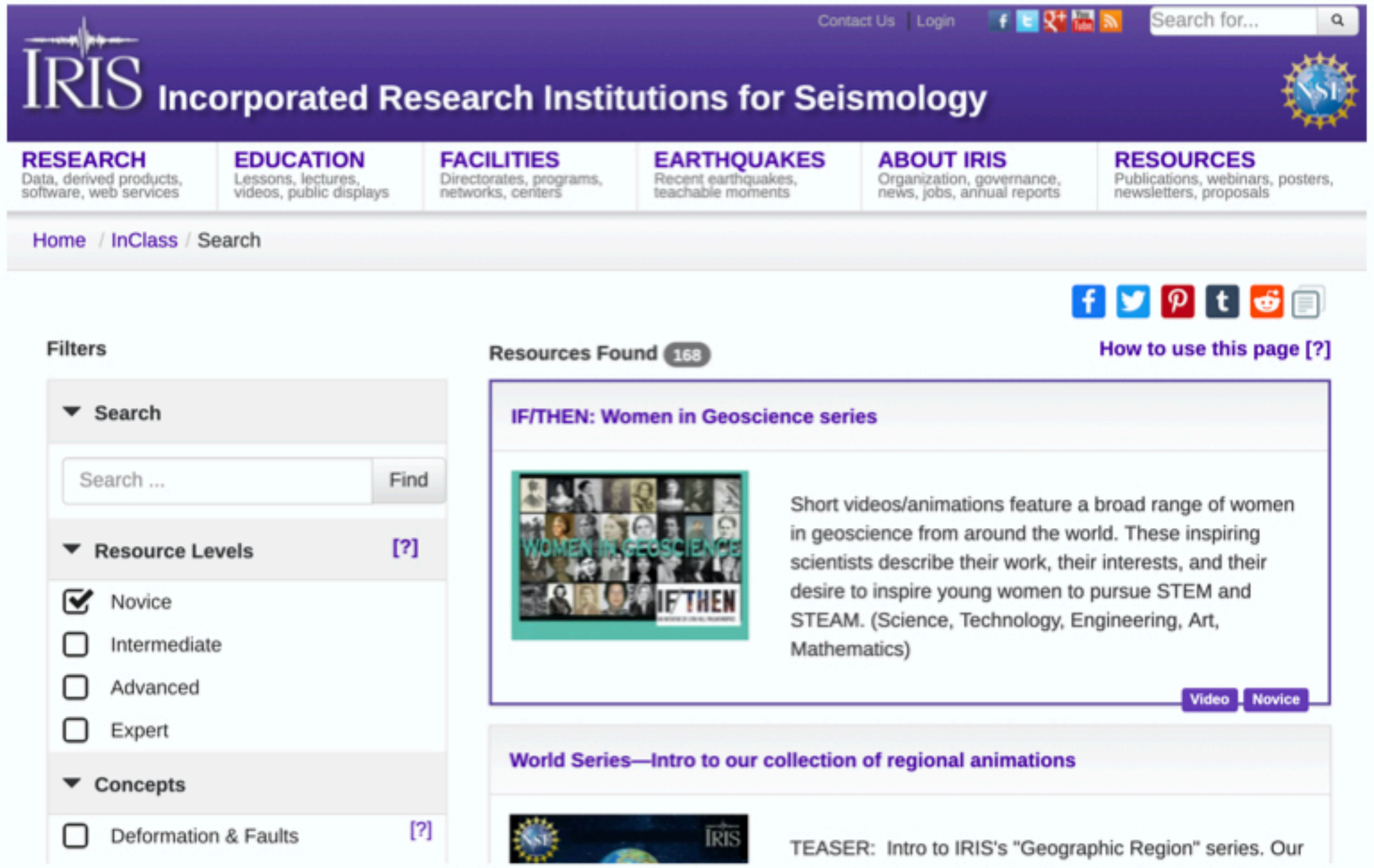
seg.georockme.com



Metamorphic Rock

meg.georockme.com





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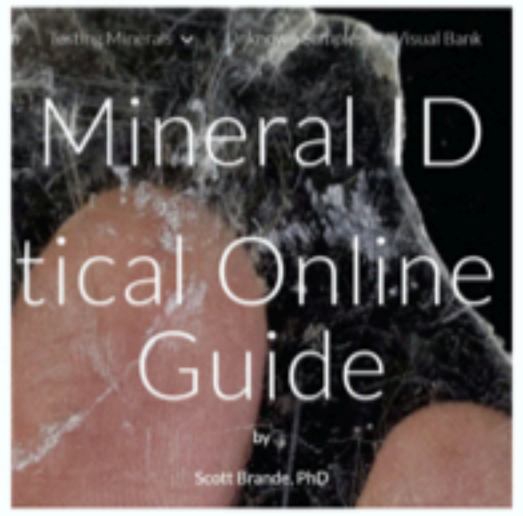

Minerals

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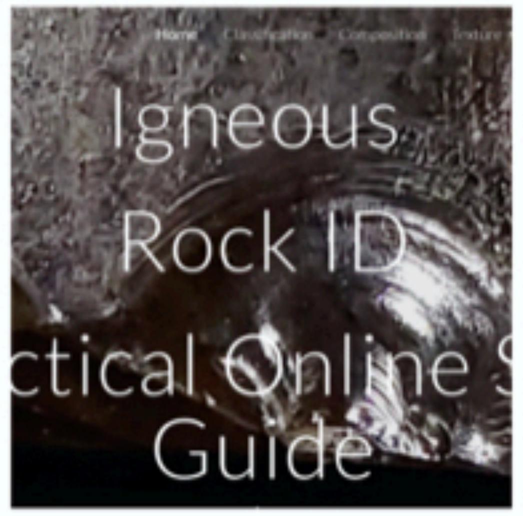
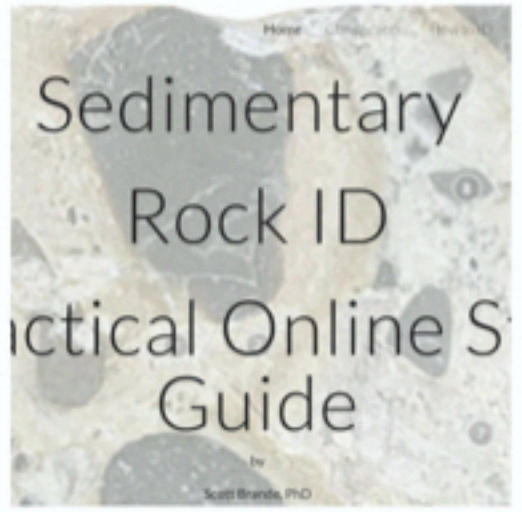


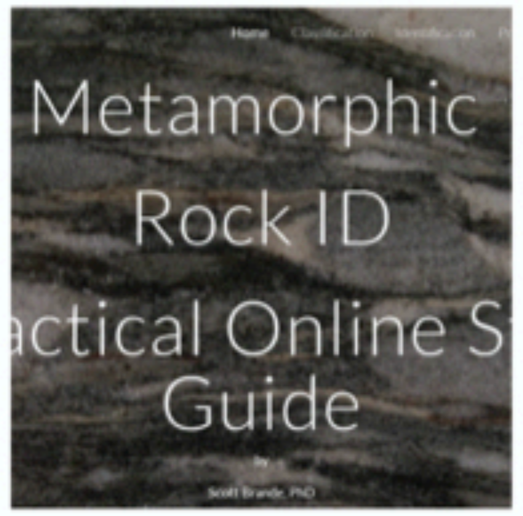
Igneous Rock

igg.georockme.com



Sedimentary Rock

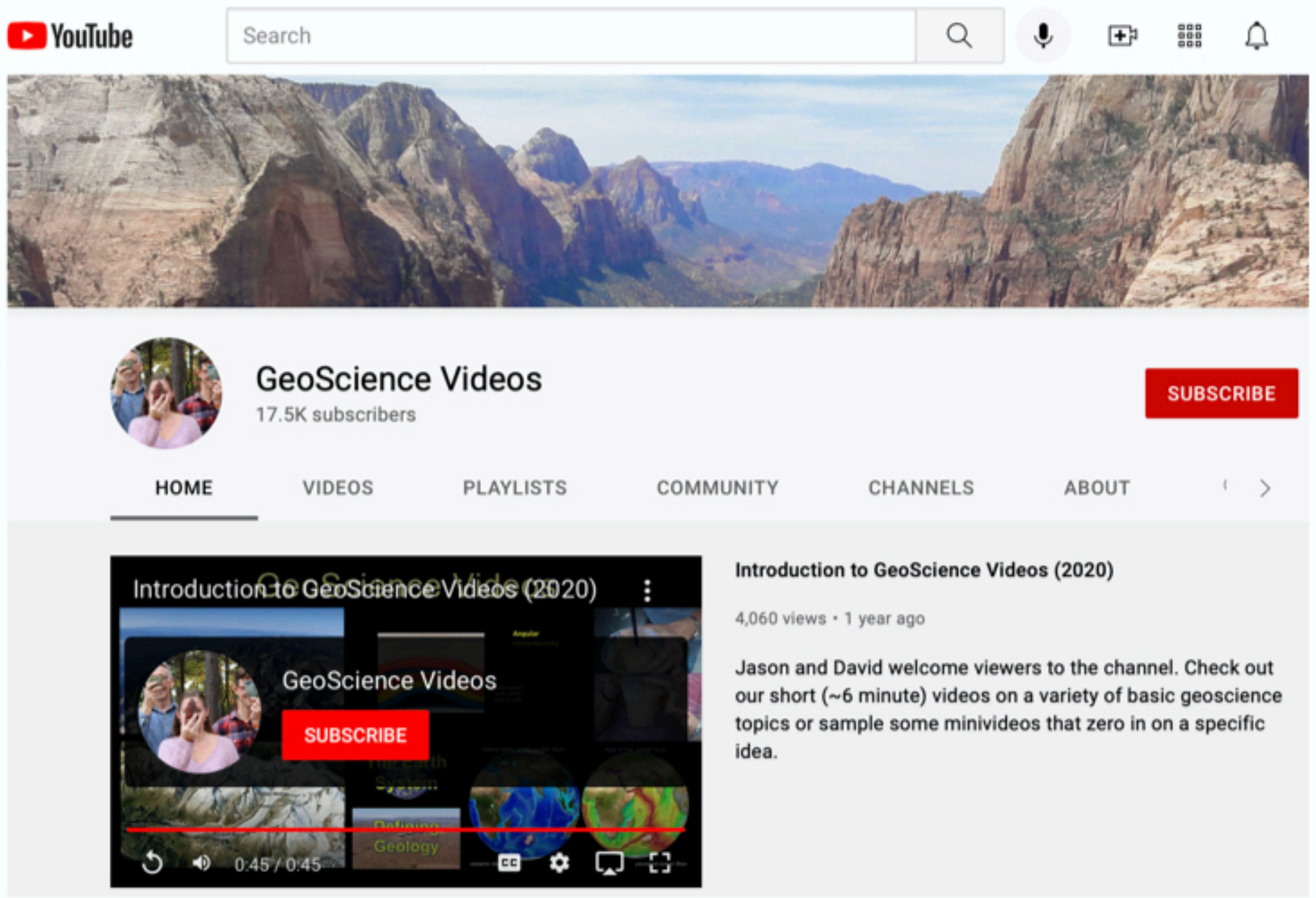
seg.georockme.com

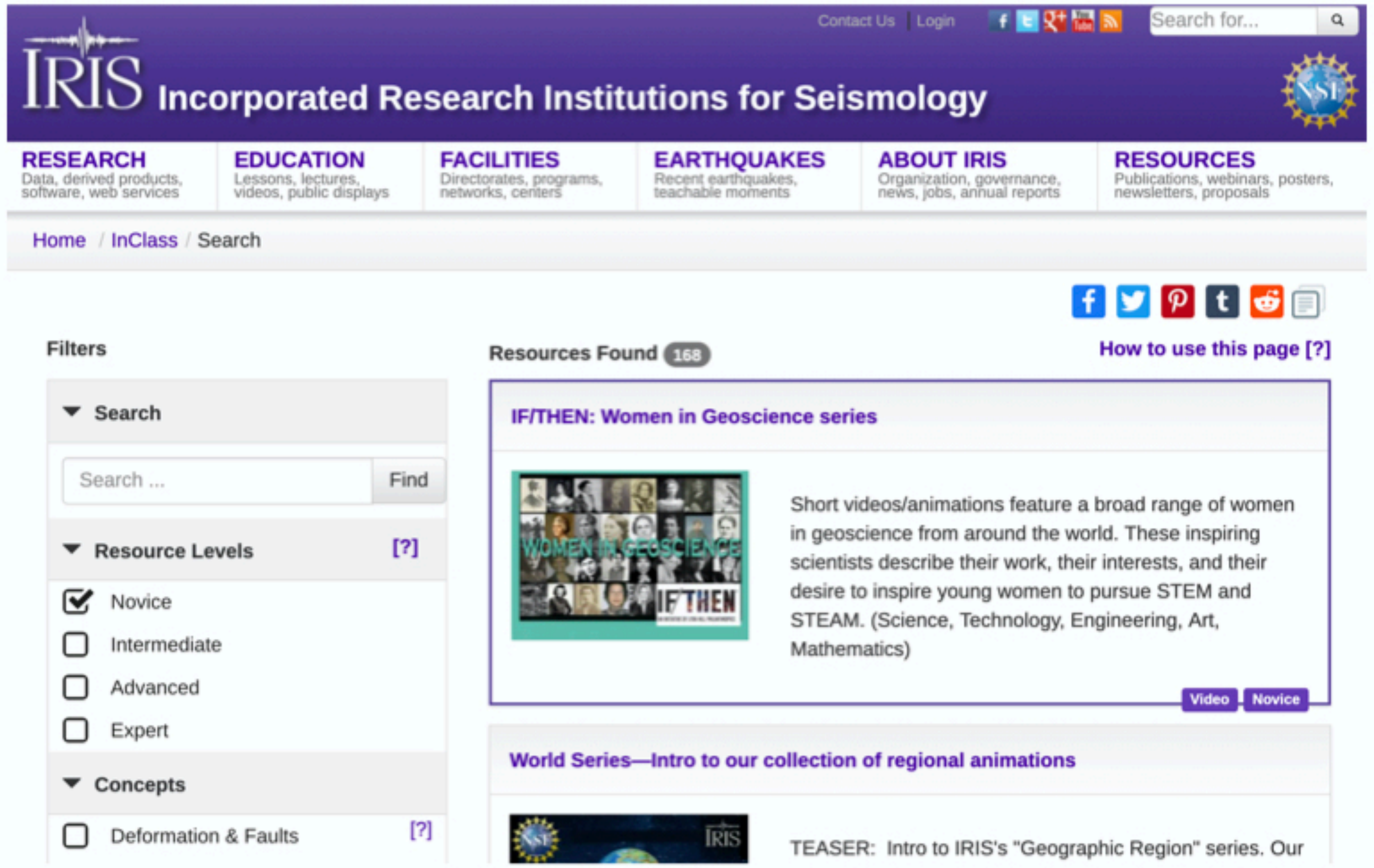


Metamorphic Rock

meg.georockme.com

https://CroninProjects.org/LabsDuringCOVID/ https://CroninProjects.org/TeacherPortal/





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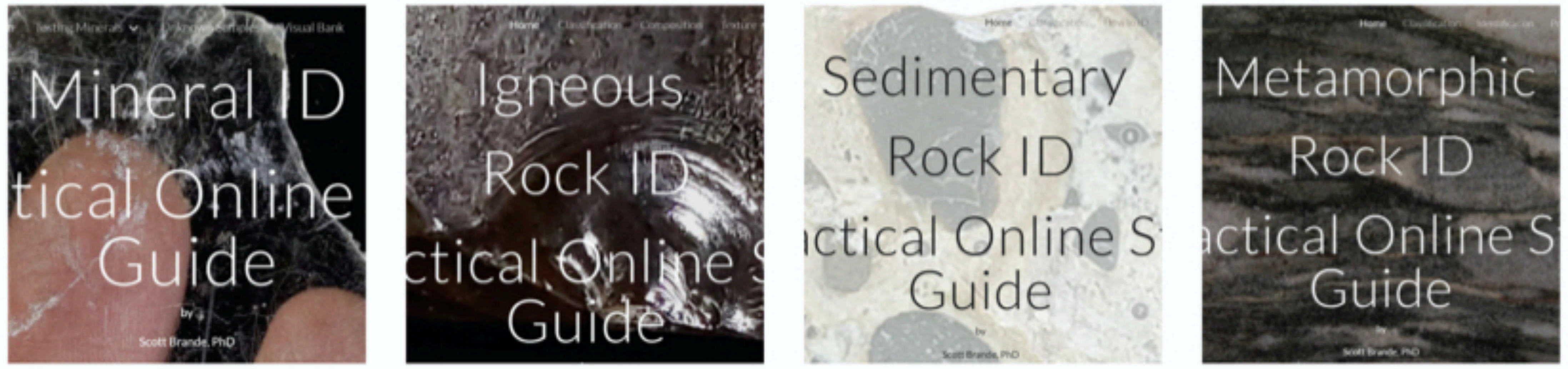


Minerals	Igneous Rock	Sedimentary Rock	Metamorphic Rock
omg.georockme.com	igg.georockme.com	seg.georockme.com	meg.georockme.com

https://CroninProjects.org/LabsDuringCOVID/ https://CroninProjects.org/TeacherPortal/

Tiny Videos Describing Unknown Specimens of Geologic Solids on Cronin-Geoscience-Ed YouTube Channel

Minerals

apatite
augite
azurite
biotite
calcite
chlorite
corundum
fluorite
galena
graphite
gypsum
halite
hematite
hornblende
malachite
muscovite
olivine
orthoclase
Ca-plagioclase
Na-plagioclase
pyrite
quartz

Igneous Solids

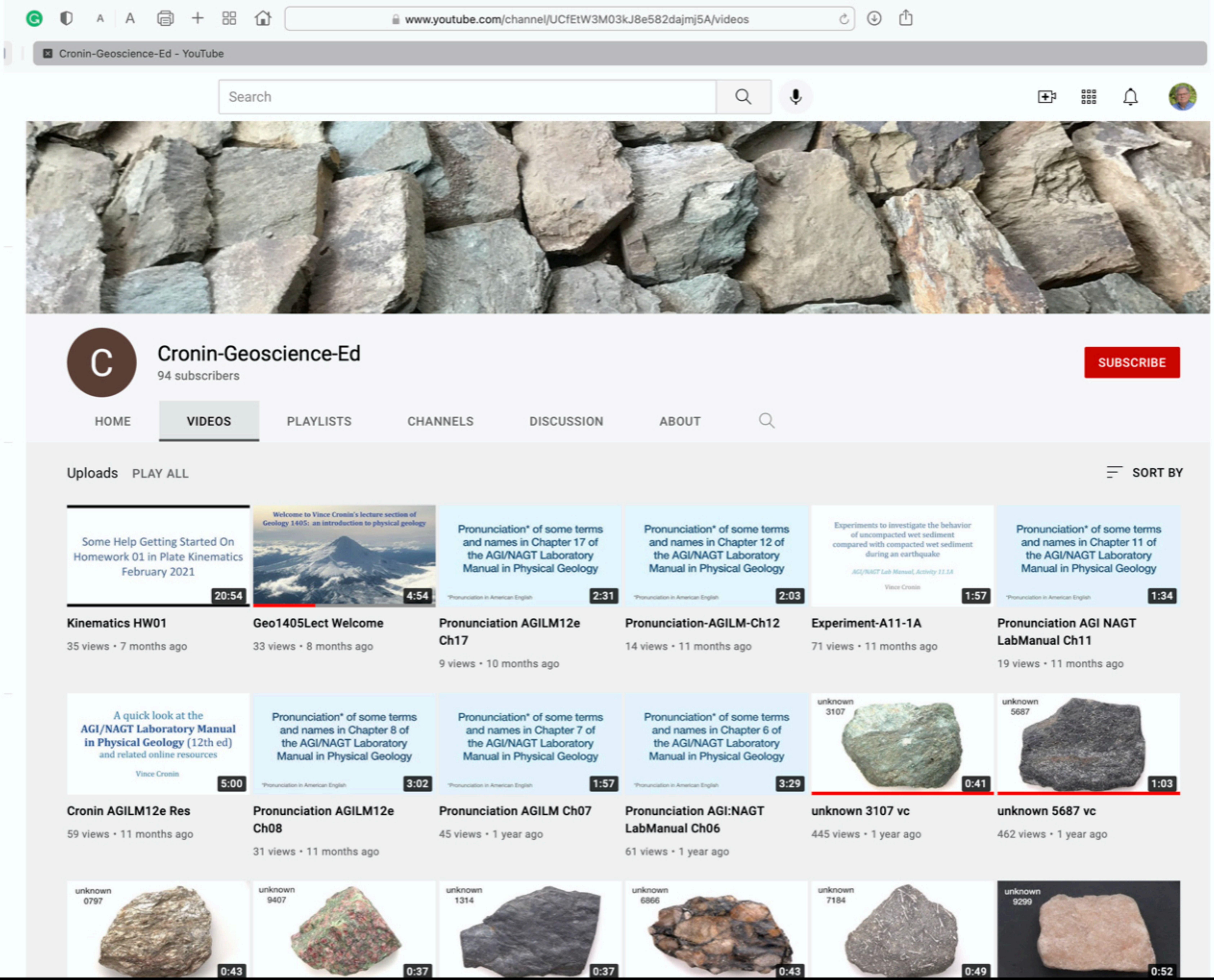
andesite
basalt (massive)
basalt (vesicular)
diorite
gabbro
granite (white)
granite (pink)
obsidian
peridotite
pumice
rhyolite

Sedimentary Solids

anthracite coal
arkose
bituminous coal
chalk
chert
claystone (kaolinite)
conglomerate
coquina
fossiliferous dolostone
fossiliferous limestone
micrite
mudstone
oolitic limestone
peat
quartz sandstone
rock gypsum
rock salt
sedimentary breccia
shale
siltstone

Metamorphic Solids

amphibolite
anthracite coal
biotite schist
blueschist
chlorite schist
eclogite
garnet muscovite schist
gneiss
marble
metaconglomerate
muscovite schist
phyllite
quartzite
serpentinite
sillimanite schist
slate



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Activity 17.2 Melting Ice and Rising Sea Level

Name: ____________________ Course/Section: ________________ Date: ____________

Learning GOAL You will use simple experiments to investigate the effects of melting continental glaciers and ice sheets versus melting ice floating in the ocean. You will consider how this melting affects sea level (if at all). You will use data from orbital satellites to explore these effects on a global scale.

A Does sea level rise, fall, or remain the same when a floating iceberg melts? To investigate this matter, either perform the following simple experiment or watch the brief video available at **https://qrgo.page.link/Mr42z**

To perform the experiment, you need a glass container, some tap water, and ice that has sufficient volume that it might have an obvious effect on the water level in the container (Fig. A17.2.1A).

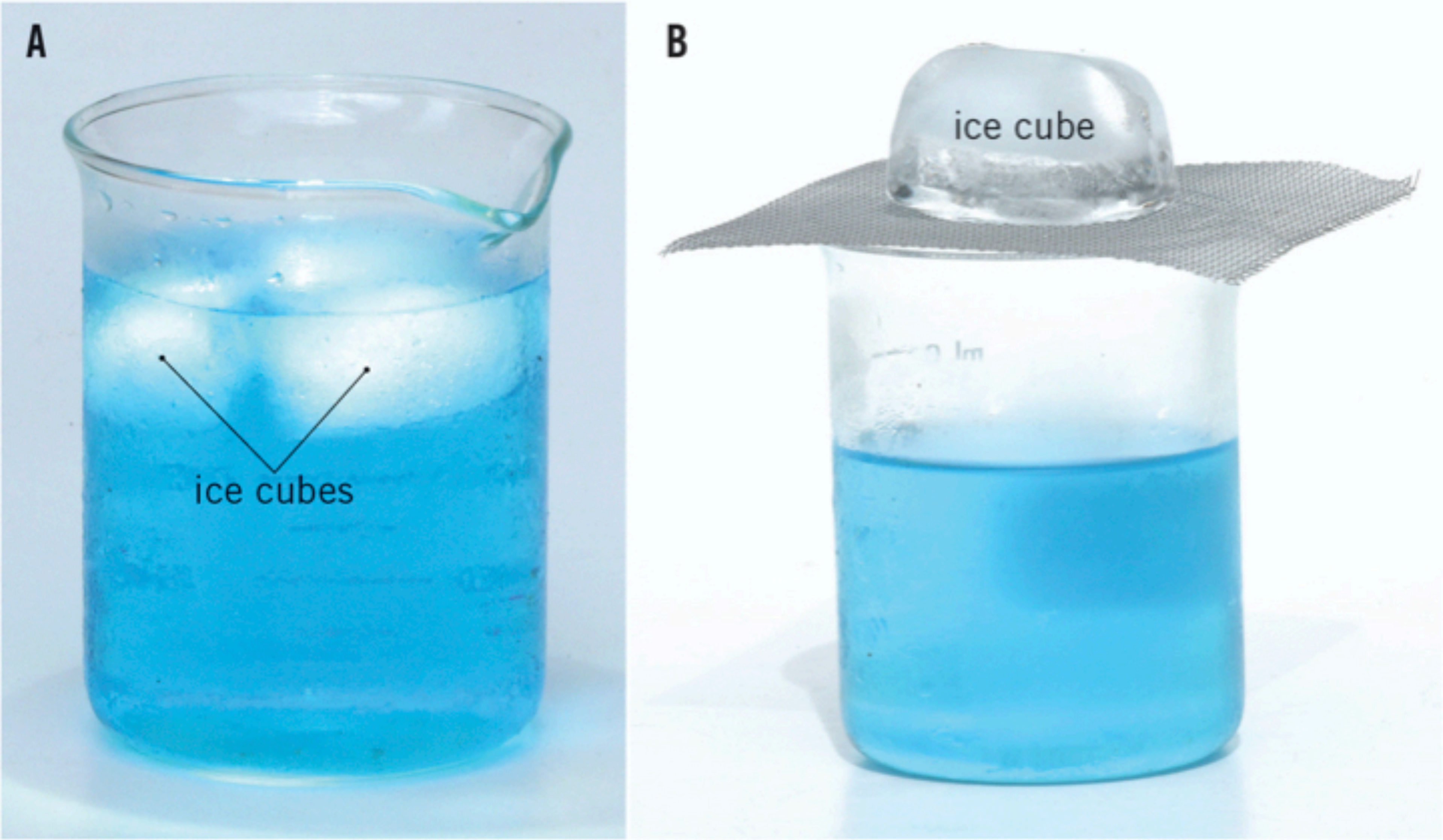


Figure A17.2.1

Step 1. Fill the container about half full of tap water and add the ice. All of the ice should be floating in the water, not touching the bottom of the container.

Step 2. On the side of the glass container, mark the level of the liquid water in the container.

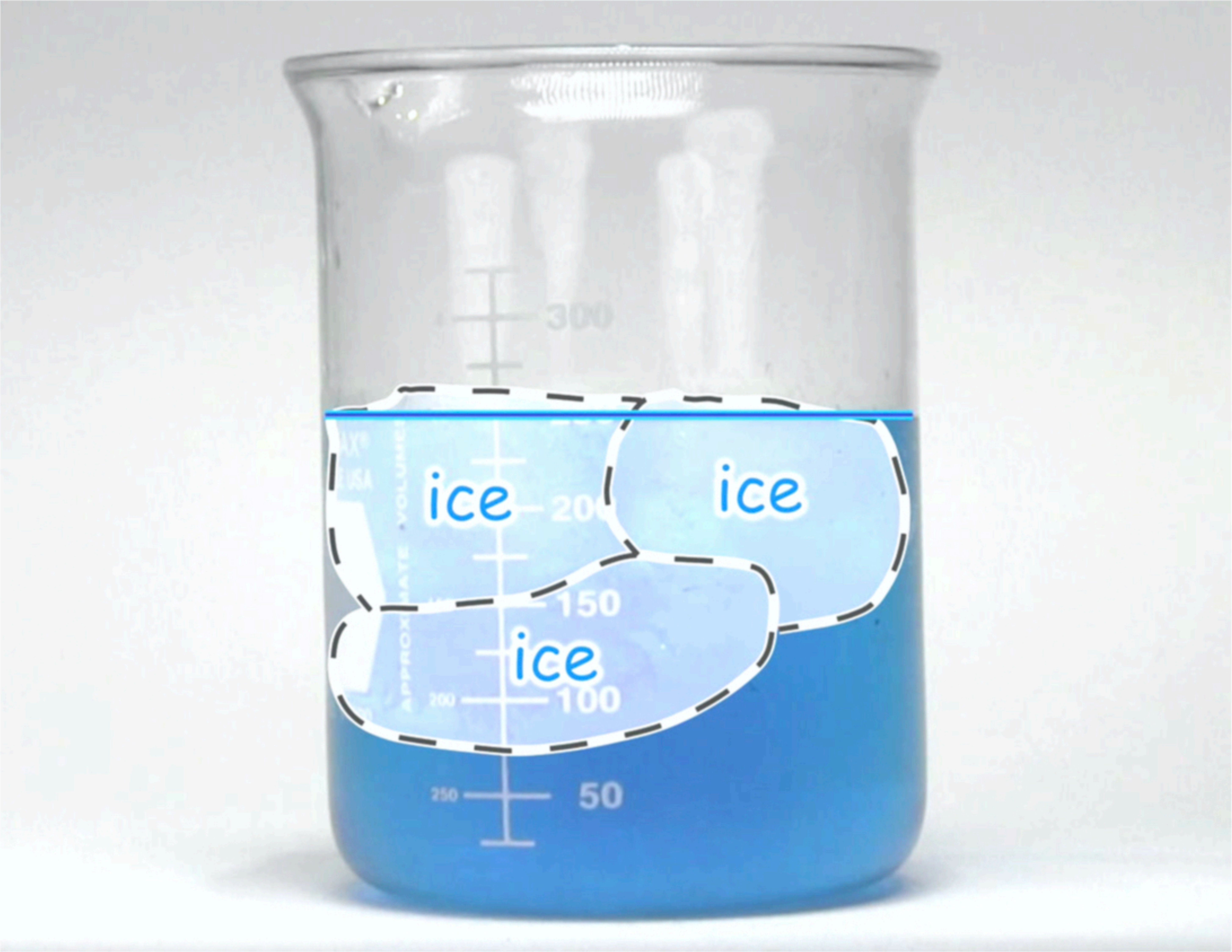
Step 3. When the ice melts completely, observe the level of the liquid water in the container.

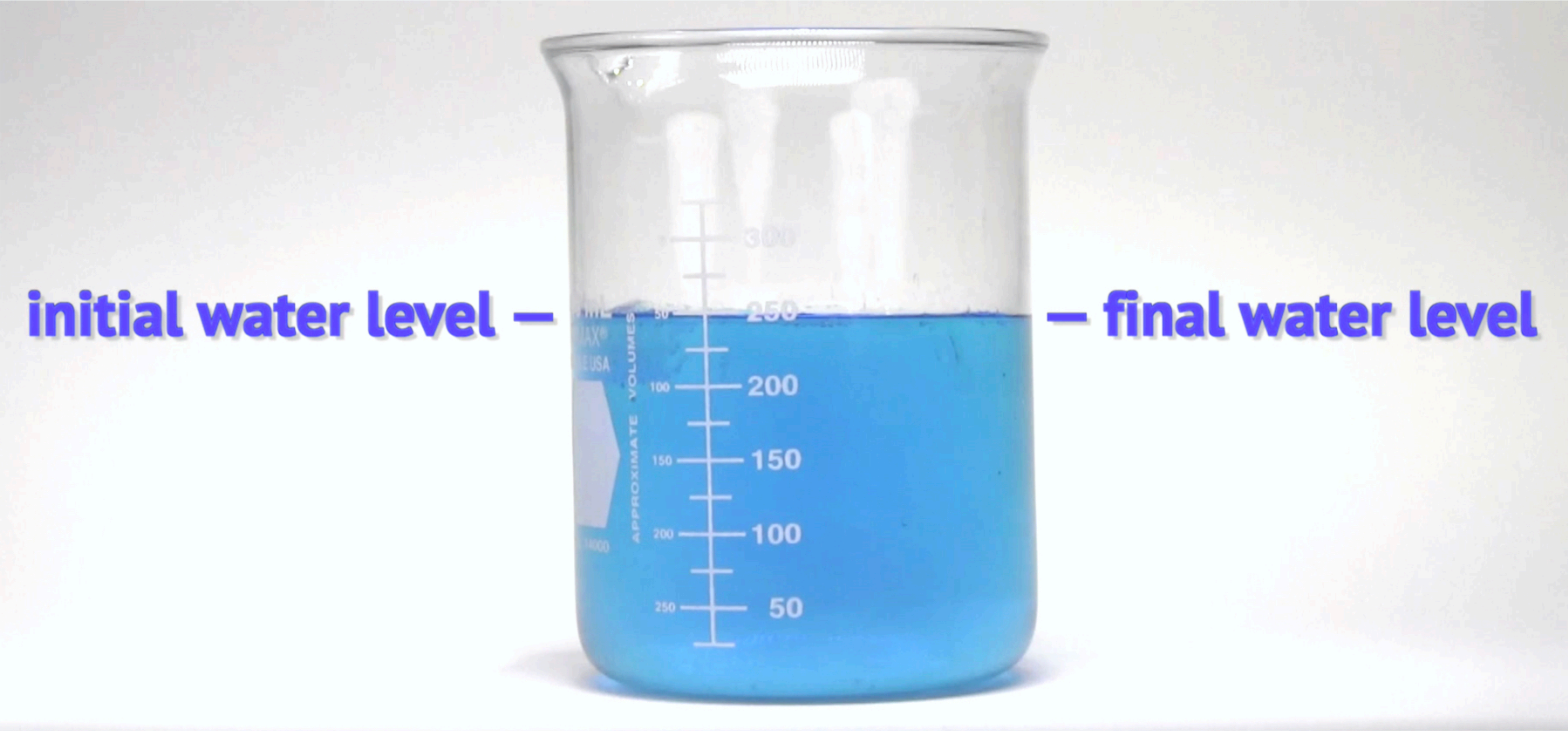
1. How did the water level in the container change, if at all, during the experiment?

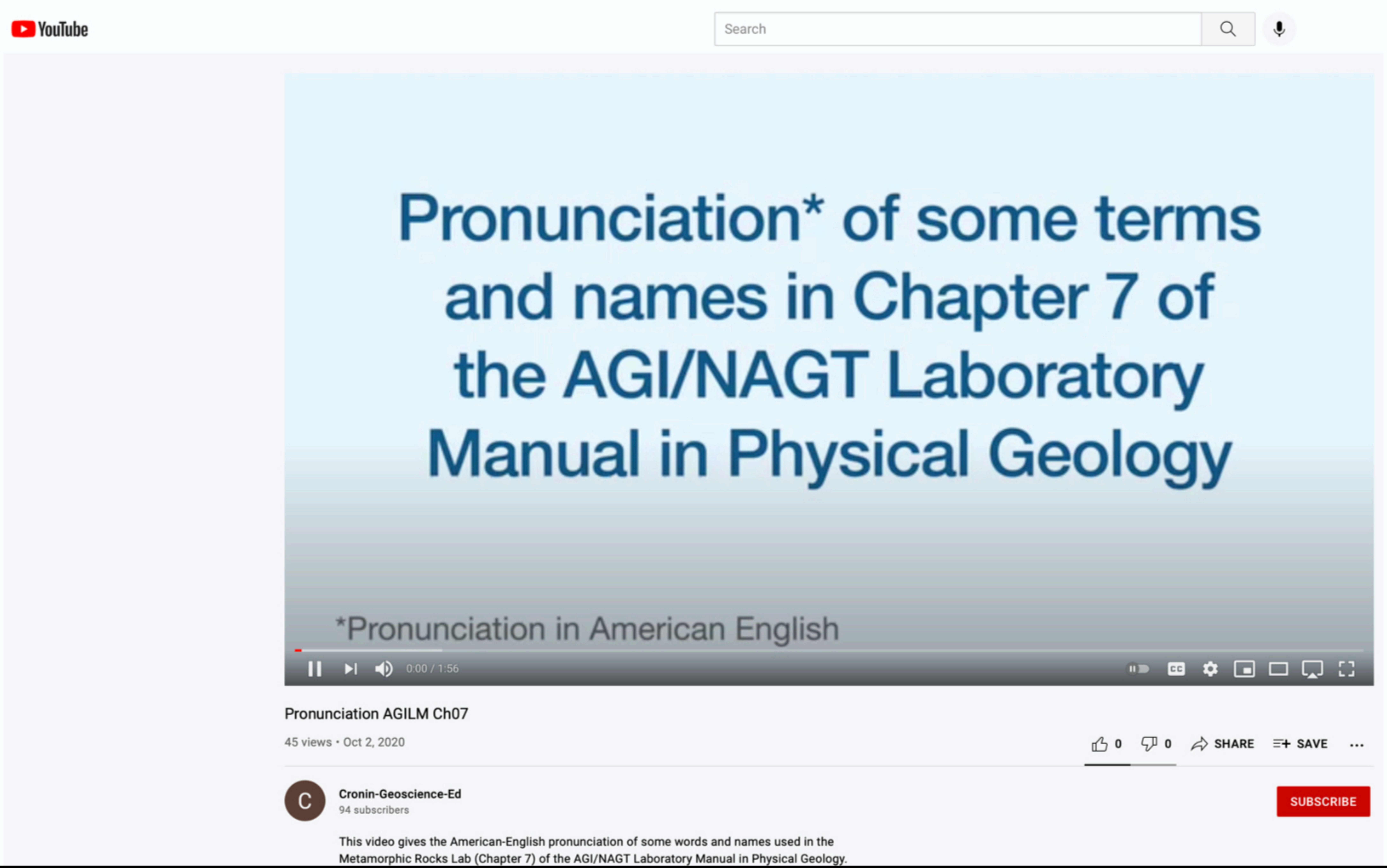
Does sea level change when sea ice or a floating iceberg melts?

Pearson


300
250
200
150
100
50
APPROXIMATE VOLUMES


ice
ice
ice
300
200
150
100
50


initial water level —
— final water level
300
250
200
150
100
50
APPROXIMATE VOLUMES
100
150
200
250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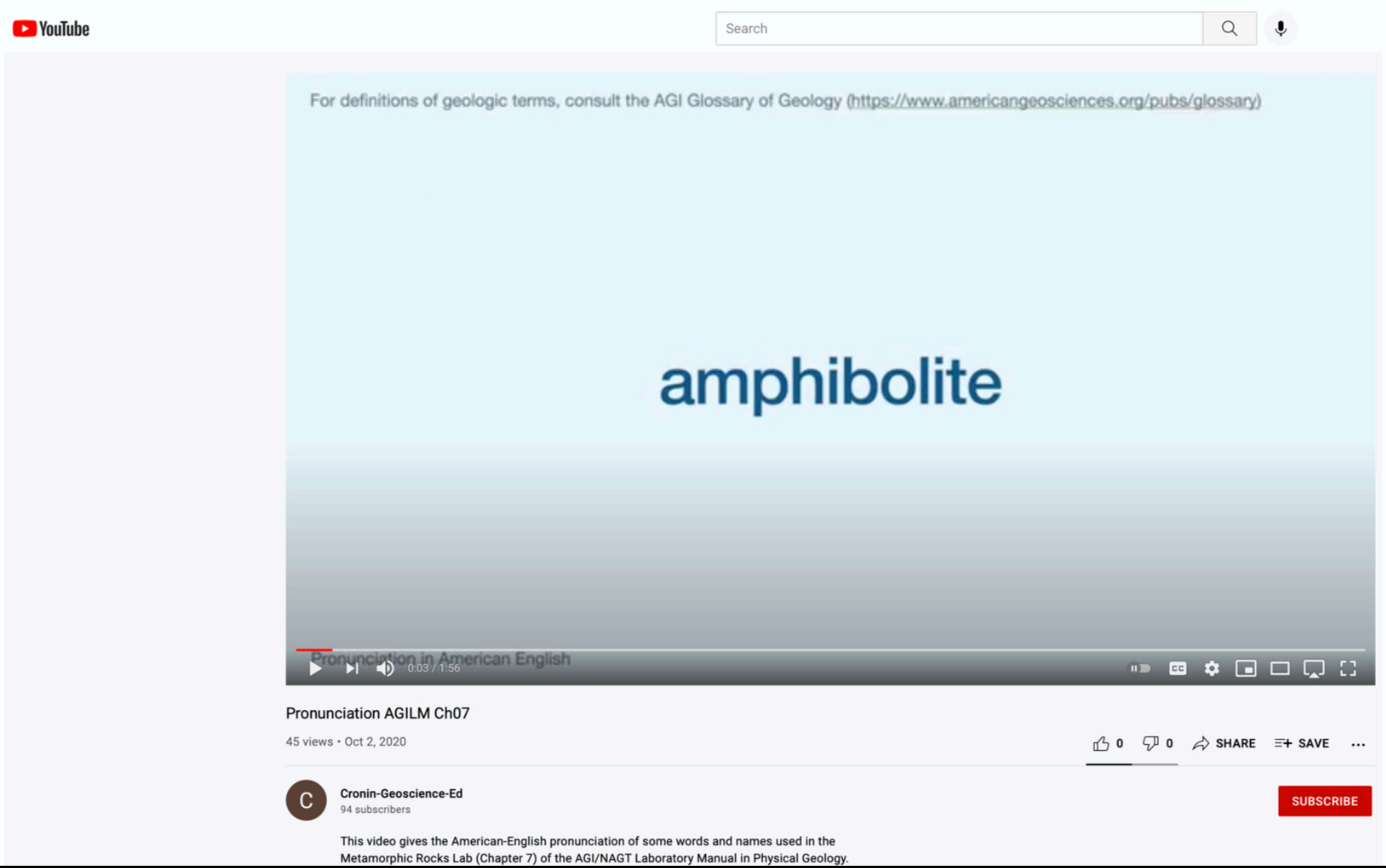
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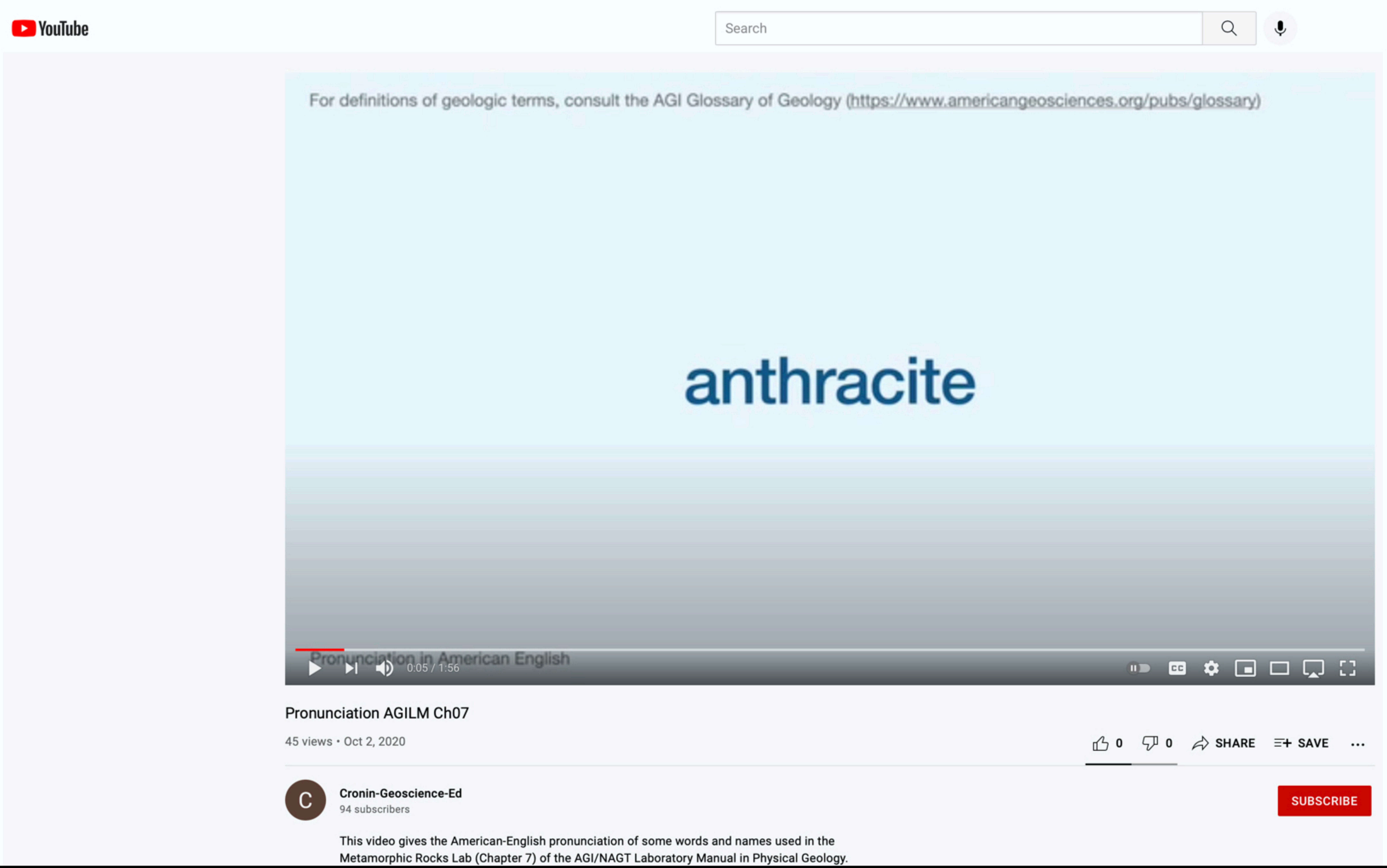
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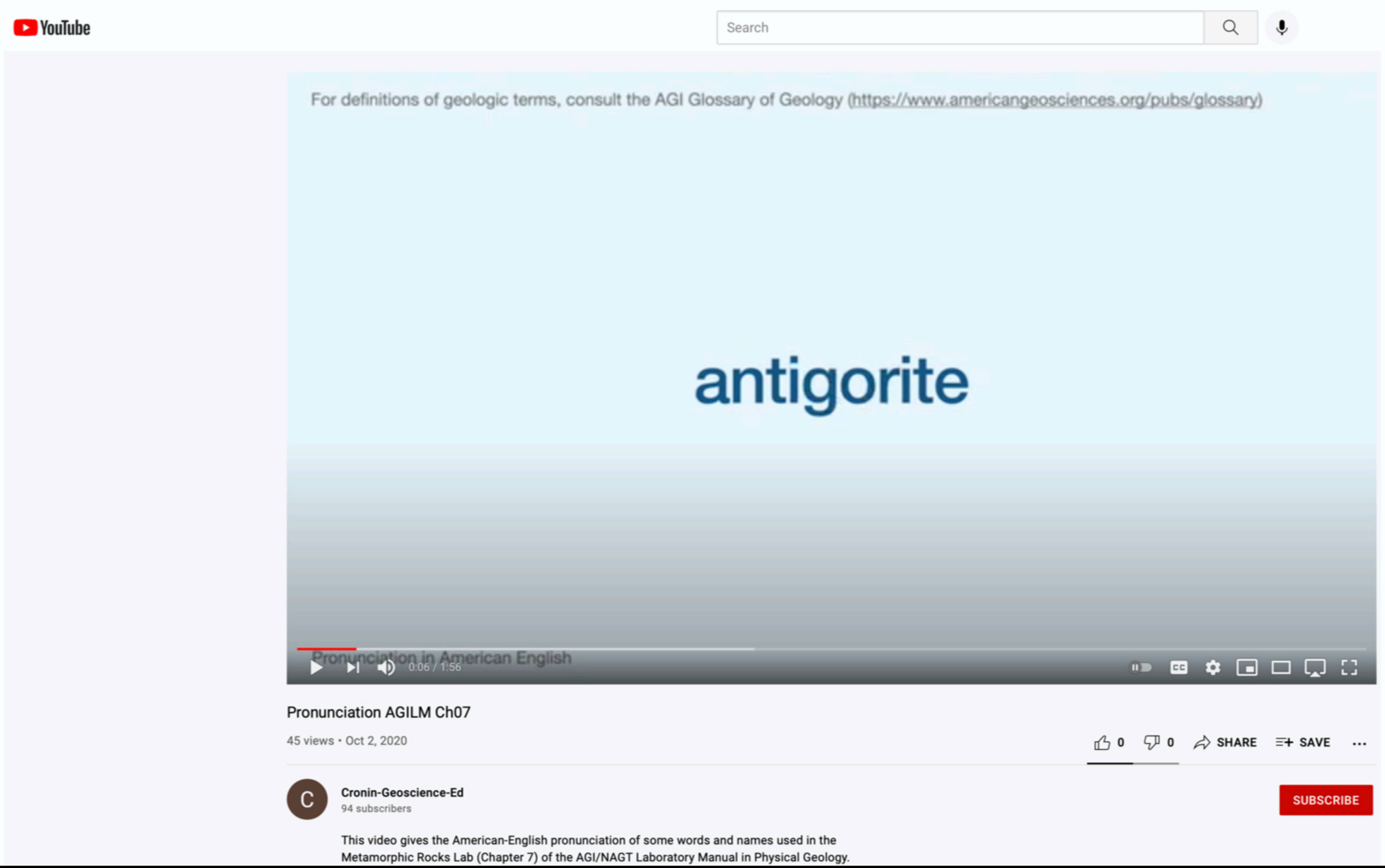
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Activity 13.3 Using Data to Map the Flow of Groundwater

Name: ____________________ Course/Section: Geo 1405 Date: 4/14/2021

Learning GOAL You will construct contours of equal total head along a line of section and use them to determine the flow of groundwater below the water table.

We want to understand how groundwater flows below the water table as viewed in a vertical plane through an unconfined aquifer. At several locations along the line of section, a set of piezometers was installed that extended to different depths. This set is called a nest of piezometers. The elevation of the open (screened) base of each of the piezometers was determined—the elevation head. The height to which the water rose in each piezometer was also measured—the pressure head. The total head can be determined by adding the elevation head and the pressure head.

The profile of the ground surface, the water table (marked by the triangles), and the total head at dozens of points along the line of section are given in **Fig. A13.3.1**. Elevations and heads are given in feet.

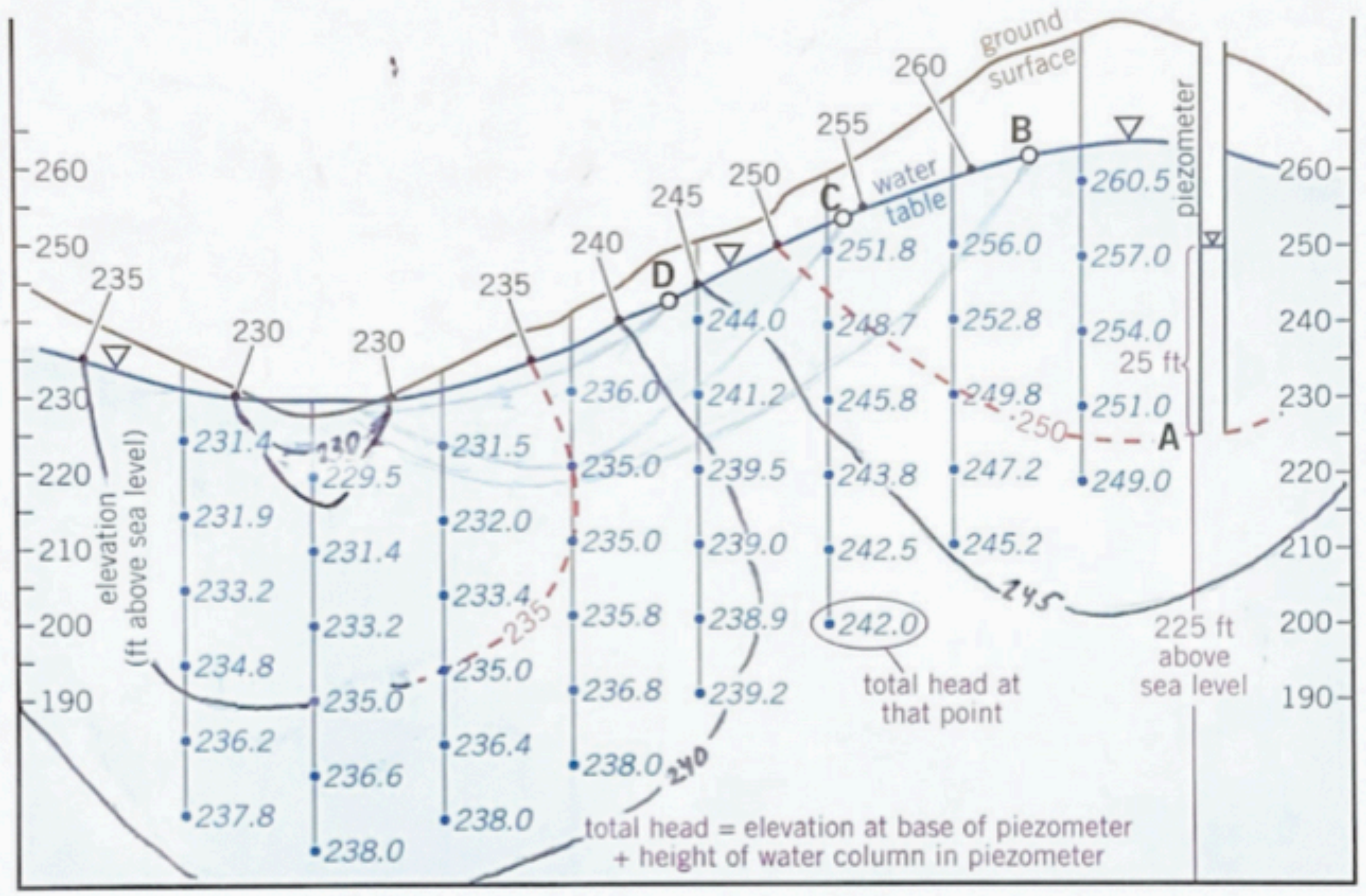

Figure A13.3.1 ▲

A Examine the piezometer on the right side of the section at whose base is point **A**.

1. What is the *pressure head* for point **A**? Refer to **Fig. 13.4** if you need help. 25 ft
2. What is the *elevation head* for point **A**? 225 ft
3. What is the *total head* for point **A**? 250 ft

Approximate Lecture Schedule

In addition to university holidays this semester (Thanksgiving, November 21-27), Professor Cronin will be out-of-town October 12-14 to participate in the Geological Society of America Annual Meeting in Portland, Oregon. There are no lectures scheduled for that week.

The referenced textbook is **Earth** by Tarbuck and others (see full reference below).

Lecture Dates	Chapter in Tarbuck *et al.*	Topic and Link to More Info	End-of-Topic Quiz Dates	Mastering Geology Assignments Due
Aug 24 – Sept 02	Chapter 01	Introduction	Practice Q: Aug27-28 Graded Q: Sept 03-04	Sept 04
Sept 07–09	Chapter 02	Plate Tectonics	Sept 10-11	Sept 11
Sept 14–16	Chapter 03	Minerals	Sept 17-18	Sept 18
Sept 21–23	Chapters 04-05	Igneous Rocks	Sept 24-25	Sept 25
Sept 28–30	Chapter 07	Sedimentary Rocks	Oct 01-02	Oct 02
Oct 05–07	Chapter 08	Metamorphc Rocks	Oct 08-09	Oct 09
Oct 12–14	—	No lecture currently scheduled for this week. GSA Annual Meeting, Portland	—	—
Oct 19–21	Chapter 09	Geologic Time	Oct 21–23	Oct 23
Oct 26–28	Chapter 10	Faults and Deformation of the Crust	Oct 29–30	Oct 30
Nov 02–04	Chapter 11	Earthquakes	Nov 05–06	Nov 06
Nov 09–11	Chapter 16	Streams	Nov 12–13	Nov 13
Nov 16–18	Chapter 17	Groundwater	Nov 19–20	Nov 20
Nov 22–26	—	No lectures this week — Thanksgiving Break	—	—
Nov 30 – Dec 07	Chapter 21	Climate	Dec 07–08	Dec 08

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Metamorphic Rocks

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Assignment

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2. ***View*** a short video by Dave McConnell and friends — ***Metamorphic Rocks and Toast***.
3. ***Scan:*** **Earth**, chapter 8, section 8.1, *What is Metamorphism?* and section 8.2, *What Drives Metamorphism?*
4. ***Read:*** **Earth**, chapter 8, section 8.6 *Determining Metamorphic Environments*, sub-section *Using Index Minerals to Determine Metamorphic Grade*
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6. ***Read:*** **Earth**, chapter 8, section 8.5 *Metamorphic Environments* and section 8.6, *Determining Metamorphic Environments*

Mastering Geology Reminder

Complete the Dyamic Study Module called *Metamorphic Rocks* and HW08 by going to *Mastering Geology* through the Canvas space associated with this lecture section (202130 GEO 1405 01 - The Dynamic Earth)

Metamorphic Rocks

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Mastering Geology Reminder

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Tentative Lab Schedule

The lab schedule is subject to revision. Reload this page in your browser to be certain that you are viewing the most current information.

Dates	Lab Manual Chapter	Topic and Link to More Info	Pre-lab Video	Assigned Lab Activities
Aug 24–26	—	No lab during the first week of class	—	—
Aug 31 – Sept 02	Chapter 01	Introduction	https://goo.gl/c3zAzr	Activities 1.1, 1.5, 1.6, and 1.7
Sept 07–09	Chapter 02	Plate Tectonics	https://goo.gl/NrcXgB	Activities 2.1, 2.2, 2.4, 2.6, 2.8
Sept 14–16	Chapter 03	Minerals	https://goo.gl/kKBN1l	Activities 3.1, 3.2, 3.3, 3.4, 3.5
Sept 21–23	Chapter 05	Igneous Rocks	https://goo.gl/EIzuX1	Activities 5.1, 5.4, 5.5, 5.7, 5.8
Sept 28–30	Chapter 06	Sedimentary Rocks	https://goo.gl/JIK8cy	Activities 6.4, 6.5, 6.6, 6.7, 6.8
Oct 05–07	Chapter 07	Metamorphic Rocks	https://goo.gl/KEp1Md	Activities 7.2, 7.3, 7.4, 7.5
Oct 12–14	—	No Labs or Lab Quizzes This Week.	—	Take an afternoon nap.
Oct 19–21	Chapter 08	Geologic Time	https://goo.gl/k3LPxG	Activities 8.2, 8.3, 8.4, 8.5
Oct 26–28	Chapter 09	Topo Maps	https://goo.gl/ymsX24	Activities 9.2, 9.3, 9.4, 9.5, 9.6
Nov 02–04	Chapter 11	Earthquakes	https://goo.gl/gMj34o	Activities 11.1, 11.2, 11.3, 11.4, 11.5
Nov 09–11	Chapter 12	Streams	https://goo.gl/225WpT	Activities 12.1, 12.3, 12.5, 12.7
Nov 16–18	Chapter 13	Groundwater	https://goo.gl/TQWzrF	Activities 13.1, 13.2, 13.3, 13.6
Nov 22–26	—	No lectures this week — Thanksgiving Break	—	—
Nov 30 – Dec 02	Chapter 17	Climate	Click HERE	Activities 17.1, 17.2, 17.4, 17.5, 17.6

Tentative Lab Schedule

The lab schedule is subject to revision. Reload this page in your browser to be certain that you are viewing the most current information.

Dates	Lab Manual Chapter	Topic and Link to More Info	Pre-lab Video	Assigned Lab Activities
Aug 24–26	—	No lab during the first week of class	—	—
Aug 31 – Sept 02	Chapter 01	Introduction	https://goo.gl/c3zAzr	Activities 1.1, 1.5, 1.6, and 1.7
Sept 07–09	Chapter 02	Plate Tectonics	https://goo.gl/NrcXgB	Activities 2.1, 2.2, 2.4, 2.6, 2.8
Sept 14–16	Chapter 03	Minerals	https://goo.gl/kKBN1l	Activities 3.1, 3.2, 3.3, 3.4, 3.5
Sept 21–23	Chapter 05	Igneous Rocks	https://goo.gl/EIzuX1	Activities 5.1, 5.4, 5.5, 5.7, 5.8
Sept 28–30	Chapter 06	Sedimentary Rocks	https://goo.gl/JIK8cy	Activities 6.4, 6.5, 6.6, 6.7, 6.8
Oct 05–07	Chapter 07	Metamorphic Rocks	https://goo.gl/KEp1Md	Activities 7.2, 7.3, 7.4, 7.5
Oct 12–14	—	No Labs or Lab Quizzes This Week.	—	Take an afternoon nap.
Oct 19–21	Chapter 08	Geologic Time	https://goo.gl/k3LPxG	Activities 8.2, 8.3, 8.4, 8.5
Oct 26–28	Chapter 09	Topo Maps	https://goo.gl/ymsX24	Activities 9.2, 9.3, 9.4, 9.5, 9.6
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Nov 30 – Dec 02	Chapter 17	Climate	Click HERE	Activities 17.1, 17.2, 17.4, 17.5, 17.6

Metamorphic Rocks Lab

This document is subject to revision, so ***reload*** this page in your browser every time you visit so that you will be certain to view the most current content. Revised October 2, 2021.

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Important Notes

- The reading assignments are in the required laboratory manual (textbook) listed near the bottom of this document.
- You must submit [1] the original paper lab-activity sheets on which you have recorded your answers (stapled together in order), and [2] a PDF file containing scans of the completed laboratory activities to your laboratory instructor before the end of your lab meeting.
- The end-of-lab quiz must be completed via the Canvas LMS within 6 hours after your laboratory meeting ends.

Lab Assignment

1. ***View*** the video introducing the material in Chapter 7 of the AGI/NAGT Lab Manual at https://goo.gl/KEp1Md
2. ***View*** the pronunciation guide for geoscience terms used in Chapter 7 of the AGI/NAGT Lab Manual at https://youtu.be/qavk7Pzv9pk
3. ***Scan*: AGI/NAGT Lab Manual**, chapter 7, the following 3 sections — [1] *Introduction*, [2] *The Metamorphic Environment*, and [3] *Grain-Scale Metamorphic Processes*, pages 183-188.
4. ***Read*: AGI/NAGT Lab Manual**, chapter 7, section *Some Important Minerals in Metamorphic Rock*, pages 188-189.
5. ***Do*: AGI/NAGT Lab Manual**, chapter 7, Activity 7.2, *Minerals in Metamorphic Rock*, page 198. If you get stuck, contact your Graduate Teaching Assistant (GTA) or Dr. Cronin and they'll try to help you get unstuck.
6. ***Read*: AGI/NAGT Lab Manual**, chapter 7, section *Metamorphic Rock Types Defined by Texture*, pages 189-192, and section *Classification Based on Composition or Context*, pages 192-194.
7. ***Do*: AGI/NAGT Lab Manual**, chapter 7, Activity 7.3, *Metamorphic Rock Analysis and Interpretation*, pages 199-200.
8. ***Read*: AGI/NAGT Lab Manual**, chapter 7, section *Description and Interpretation of Metamorphic Hand Specimens*, p. 194-195.
9. ***Do*: AGI/NAGT Lab Manual**, chapter 7, Activity 7.4, *Hand Sample Analysis, Classification, and Protolith*, pages 201-203.

   Identify these specimens, in the order given, on page 201 of the **AGI/NAGT Lab Manual**:
   that is shown online at

   - Unknown metamorphic specimen 01 — same specimen type as unknown 0797 that is shown online at https://youtu.be/qLZo3dm4kcs
   - Unknown metamorphic specimen 02 — same specimen type as unknown 9299 that is shown online at https://youtu.be/pqyMJ6XXh5w
   - Unknown metamorphic specimen 03 — same specimen type as unknown 4802 that is shown online at https://youtu.be/sUQKpzViIR8
   - Unknown metamorphic specimen 04 — same specimen type as unknown 1314 that is shown online at https://youtu.be/wfgw1k3F61w
   - Unknown metamorphic specimen 05 — same specimen type as unknown 6874 that is shown online at https://youtu.be/jlKN9x4Mfu4

   Identify these specimens, in the order given, on page 202 of the **AGI/NAGT Lab Manual**:

   - Unknown metamorphic specimen 06 — same specimen type as unknown 1784 that is shown online at https://youtu.be/sqxRSHpoMCQ
   - Unknown metamorphic specimen 07 — same specimen type as unknown 5687 that is shown online at https://youtu.be/KfCcFf7VLss
   - Unknown metamorphic specimen 08 — same specimen type as unknown 9438 that is shown online at https://youtu.be/NXAgQUjyR4E
   - Unknown metamorphic specimen 09 — same specimen type as unknown 3107 that is shown online at https://youtu.be/IBtTaDCux6c
   - Unknown metamorphic specimen 10 — same specimen type as unknown 3649 that is shown online at https://youtu.be/K1zXXbYS41o

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- Unknown metamorphic specimen 05 — same specimen type as unknown 6874 that is shown online at https://youtu.be/jlKN9x4Mfu4

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Identify these specimens, in the order given, on page 203 of the **AGI/NAGT Lab Manual**:

- Unknown metamorphic specimen 11 — same specimen type as unknown 3222 that is shown online at https://youtu.be/B1HC-1HAM_I

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This video shows some of the physical characteristics of specimen 0797 that can be used to identify it.


PIE A PREZ


The unknown rock specimen contains this mineral
unknown metamorphic rock 01
https://youtu.be/qLZ03dm4kcs
unknown_0797_vc

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SAMSUNG
muscovite
plagioclase feldspar

Students working together on lab activities from the AGI/NAGT Lab Manual. Photo by Vince Cronin.

Vince Cronin's resources for the AGI/NAGT Lab Manual [12th Ed]

Reload this page in your browser to be certain that you are viewing the most current content.

This is the portal through which I share resources I use or have developed to support online teaching/learning with the AGI/NAGT Lab Manual. I use the Lab Manual for face-to-face and distance learning at Baylor University.

Lab 1: Filling your Geoscience Toolbox

- Pre-lab video: Thinking like a geologist — https://goo.gl/c3zAzr
- Assignment from Cronin's online class, fall 2020: https://croninprojects.org/Vince/PhysGeoLab/IntroLab-F20.html
- Video pronunciation guide for names and geoscience terms used in the first chapter of the AGI/NAGT Lab Manual: https://youtu.be/032deO39fmw

Lab 2: Plate Tectonics

- Pre-lab video: Plate tectonics and the origin of magma — https://goo.gl/NrcXgB
- Assignment from Cronin's online class, fall 2020: https://croninprojects.org/Vince/PhysGeoLab/TectonicsLab-F20.html
- Video pronunciation guide for names and geoscience terms used in the Plate Tectonics Lab (chapter 2) of the AGI/NAGT Lab Manual: https://youtu.be/zMpB3c7le9c

Lab 3: Mineral Properties, Identification, and Uses

- Pre-lab video: Mineral properties, identification, and uses — https://goo.gl/kKBN1l
- Assignment from Cronin's online class, fall 2020: https://croninprojects.org/Vince/PhysGeoLab/MineralsLab-F20.html
- Video pronunciation guide for names and geoscience terms used in the Minerals Lab (chapter 3) of the AGI/NAGT Lab Manual: https://youtu.be/QbwO_4EaJJ8
- Videos of experiments done in Activity 3.4 of the AGI/NAGT Laboratory Manual in Physical Geology [12th edition
  - unknown specimen 1275 — https://youtu.be/wWm_NGtwjx8
  - unknown specimen 5096 — https://youtu.be/Nzb90fUtm50
  - unknown specimen 6295 — https://youtu.be/rh277hP4BFQ
- Videos of unknown minerals, accessible on the Cronin-Geoscience-Ed channel on YouTube (https://www.youtube.com/channel/UCfEtW3M03kJ8e582dajmj5A/).
  - Unknown 1155 as shown online at https://youtu.be/yUvEgZCm0F8