NATALIE BURSZTYN • DIANE CLEMENS-KNOTT

Reading the Rocks: The Geology of National Parks as a Platform for Climate Change Education

ABSTRACT

In this case study we describe the integration of climate change education into a college-level General Education course entitled *The Geology of National Parks* at California State University, Fullerton. By focusing on developing student observation and interpretation skills in the examination of national park rocks and landscapes, the assignment structure guides students to understand and contrast the longevity of geological processes with that of recent, rapid, anthropogenic change. Through a series of scaffolded writing exercises, including observational analysis, creation of interpretive signage, and analysis of satellite imagery, students learn to distinguish between observations and interpretations, connect geological processes to past climate conditions, and recognize evidence of rapid, human-induced climate change. This approach fosters critical thinking and scientific literacy while engaging students with America's national parks, including (but not limited to) Bryce Canyon, Zion, Grand Canyon, Yosemite, and Glacier. This case study serves as a guide for others who would like to incorporate similar assignments into their own courses and includes instructions for these activities that other instructors can use or adapt for their own context.

INTRODUCTION

***The Geology of National Parks* is a course taught at many universities in the United States, typically fulfilling part of the General Education (GE) program rather than serving as a requirement for a major in Earth or Geosciences.** The purpose of most GE courses is to prepare students with knowledge and skills from a broad array of disciplines that will serve them in their future, no matter their chosen degree path. Lifelong skills from a GE program, such as critical thinking, problem solving, effective communication, and broadening knowledge, are commonly included, as they aim to empower students to contribute effectively to a culturally diverse society. In this case study we share how we have used the geoscience perspective and teaching activities designed for our GE curriculum within the context of The Geology of National Parks to communicate climate change concepts to our undergraduate students.

THE COURSE

At California State University, Fullerton (CSUF), The Geology of National Parks is a three-credit upper division (300-level) GE course that typically enrolls around 80–100 students. Overarching course goals include learning how to:

- Scientifically observe the physical world;
- Interpret observations from a geoscientific perspective; and
- Develop an appreciation of the concept of deep geologic time.

Finally, an underlying course goal is to familiarize GE students with how new scientific knowledge is generated and to motivate them to participate in and critically evaluate current discussions of climate change, especially those in which interpretations of scientific data are being challenged by disinformation. The course's two objectives are tailored to address the goals. The first focuses on using scientific inquiry and methods to understand the geologic processes that formed the iconic rocks and landscapes of the US national parks, such as the different global and/or local climates. The second helps students to build understanding of the extent of past environmental changes.

These goals and objectives also address CSUF's GE objectives,[1] which are for students to be able to:

- Understand broad, unifying themes in science from cross-disciplinary perspectives (in this context, scientific observations and geologic interpretations);
- Solve complex problems that require scientific reasoning (reconstructing the geologic history of US national parks from an incomplete rock record); and
- Relate science to significant social problems or to other related disciplines (differentiating between the extent and rate of past environmental change from those of current climate change)

POV: YOU'RE A GEOLOGIST

As a geologist, when you look around anywhere outside you are balancing in your mind the dynamic roles of

OVERLEAF **Red Canyon, Bryce Canyon National Park, Utah (see also Figure 1).** NATALIE BURSZTYN

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climate and tectonics over time to interpret the formation of the landscape. For geologists, geoscientific thinking always includes the concept of *deep time*. We look at rocks and landscapes and think about them in terms of tens of thousands to billions of years. Within a GE program, geological deep time is not comparable to the hundreds of years covered in a history class or thousands in anthropology or archaeology. Even comparing the duration of tens of thousands of years to five hundred or one thousand years is something the human brain is generally not good at,[2] yet Earth scientists regularly consider processes taking tens of thousands of years (e.g., glacial) or millions (e.g., mountain building) or even hundreds of millions (e.g., supercontinent cycle). For example, to Earth scientists the adjective *glacial* means "so fast it is almost instantaneous," whereas in everyday speech it implies "excruciatingly slow." The conflict between human and geologic timescales makes differentiating between the rate, extent, and cycles of geologic climate changes versus those of the anthropogenic climate change we are now experiencing one of the most important lifelong skills that we can teach our GE students. This educational goal is of particular social significance since it is not uncommon for a GE geology course to be the only physical science course a student will take to complete their bachelor's degree and thus potentially their only collegiate opportunity to examine issues of climate change in a scientific context.

STRATEGY FOR SCAFFOLDED WRITING EXERCISES

In order to explore recent climate change within this GE course, one that has no Earth science prerequisite, three fundamental pieces of information are necessary: (1) Earth processes operate on widely variable timescales that include slow, natural changes in climate (geologic timescale) in contrast with rapid, anthropogenic-driven climate change (historical timescale); (2) there is a difference between weather (short-term; annual) and climate (average of weather over three or more decades);[3] and (3) Earth scientists come to "know what they know" through a rigorous scientific process that includes distinguishing between observations and interpretations. We can use the appeal of national parks to transform admiration into observation, to apply logical deductive reasoning to make geological interpretations, and to have our students practice effective communication by writing their version of interpretive education signs for various parks—which we will refer to hereafter as *Education Sign Exercises*.

The unstated major underlying theme of this suite of Education Sign Exercises is to explain the significance or importance of each location. Earth's climate at a single geographic location can change dramatically over extremely long time periods. From course content, students should be able to explain the importance, as follows: natural climate change happens due to factors such as plate tectonics, ocean circulation, volcanism, extraterrestrial impacts, and solar radiation. Earth's climate is now changing more rapidly than can be attributed to these geologic processes. Students should be able to identify and explain that recent, rapid climate change is happening due to factors such as increasing average atmospheric temperatures leading to less glacial ice, increased sea level, changing weather patterns, and increased incidences of wildfire. They also must be able to make connections to the documented recent increase in global average atmospheric temperature, which is in part linked to post-Industrial Revolution, anthropogenic changes in atmospheric chemistry.

The activities presented in this case study are sequenced in the order they were taught, scaffolded to build upon each other as the students develop their geoscientific critical thinking skills. We begin with developing and describing observations with "What Do You See?" (addressing the first and third pieces of fundamental information). This activity includes an observations-interpretations table that is designed to have students practice the first steps of the scientific method by distinguishing between observations and interpretations. This activity addresses the first steps of how scientists know what they know and prepares our students for the Education Sign assignments that they will complete throughout the rest of the course. These Education Sign Exercises require students to practice communicating how observations and interpretations support explanations of how geologic processes have formed a landscape and potentially the timescale over which such changes occur. These activities address the scope of geologic time, duration of geologic processes, and dramatic climate change over extremely long timescales in contrast with that of climatic change in recent history. Finally, related exercises using repeat photography and satellite imagery help students observe both annual changes (i.e., weather) and 40–100 years of change (i.e., climate) that have impacted land surface cover (e.g., ice, water, vegetation). For a GE course, we recommend starting with at least one iteration of "What Do You See?" before introducing any of the variations on the Education Sign Exercises.

ACTIVITY 1: WHAT DO YOU SEE?

Learning to "read the rocks" begins with making accurate observations, which is much more challenging than most would suppose. Often students, when shown a photograph, will answer the prompt "describe what you see" by jumping to an interpretation, such as “an earthquake happened,” rather than offering an accurate description of what they observe. Getting students to understand that there is a fundamental difference between observations and interpretations is a critical first step in developing their capacity for geologic inquiry. Accordingly, in the first few weeks of the semester, The Geology of National Parks students were tasked with in-class exercises of describing what they see in photos from a park on one half of their page, then interpreting what those observations might mean on the other half. For example, a photo from Bryce Canyon National Park depicting the famous hoodoos (Figure 1) was used to elicit observations that include descriptions of horizontal stacked layers of reddish-tan rocks, and vertical towers that bulge in and out.

Identifying features that can be pointed out to the viewer as observations is paramount. Once articulated, we can use our introductory-level knowledge of geologic processes to interpret the observations: sedimentary rock layers, erosion along vertical cracks or joints. Students are often quick to decide that “erosion happened” or even that some layers are “hard” and others are “soft”—which are inferences, not observations. We built on these ideas to guide the development of a more well-reasoned interpretation: that some layers are more easily eroded, or more susceptible to erosion, than others.

For these activities, students were instructed to come up with three to five observations and provide one interpretation for each observation (Figure 2). In some cases, multiple observations may have the same interpretation, a consistency that we pointed out likely strengthens that interpretation. Students were encouraged to discuss with each other and make revisions before submitting their work. For our large GE course, students submitted these assignments for participation or attendance credit, but they were not individually graded. Class discussion to address key points and answer questions or examine alternate viewpoints always followed to ensure students had opportunities to document corrections to their work. A formatted observations/interpretations example for the Kaibab Limestone in Grand Canyon National Park, Arizona, is provided in Figure 2.

Observations (what you see)	Interpretations (what observations mean)
1. horizontally layered rock	1. possibly sedimentary rock
2. cliff-forming rock	2. strong rock type
3. cream colored rock	3. consistent with limestone or sandstone
4. marine fossils	4. consistent with limestone or sandstone

FIGURE 2. Observations/interpretations exercise for the Kaibab Limestone at Grand Canyon National Park, Arizona. DIANE CLEMENS-KNOTT

FIGURE 1. Red Canyon, Bryce Canyon National Park, Utah. NATALIE BURSZTYN

Observations and interpretations like these at Bryce Canyon and Grand Canyon National Parks can be applied to numerous other national parks as well as other observable features in our students’ daily lives, including building stone, freeway roadcuts, headstones in cemeteries, and local mountains. We assigned this observation-interpretation activity twice. This provided the framework necessary for students to complete the subsequent Education Sign Exercises throughout the remainder of the course.

ACTIVITY 2: EDUCATION SIGN EXERCISES

Once students are sufficiently adept at differentiating observations from interpretations, they have the fundamental skills necessary to compose interpretive signage that can inform park visitors about the natural history of the area. The Education Sign Exercises are first introduced to students by describing a scenario:

> Imagine you're visiting a national park with your friends or family who have never taken a geology class. Your goal is to teach them something you've learned about geology that is also somehow related to what you are looking at. Capture their attention by pointing out something they can see, explain what they are seeing, and how that feature formed. You want them to take a picture and walk away thinking, "I didn't know that—how cool!"

Like the observations and interpretation exercises in our large GE course, the Education Sign Exercises were submitted for participation credit with class discussion always following to ensure that key points (i.e., geological interpretations of observations) and any questions were addressed, while also providing students the opportunity to revise their work.

We started out with Education Sign Exercises that were simpler. These initially consisted of a composed version of the observation/interpretation activity and later built to more complex and applied ideas as students develop knowledge. In class, prior to the exercises, photos of related and/or similar features are shown, described, and discussed within the context of the geology of that national park. We do not expect students to create new knowledge when writing an Education Sign, but rather to extract pertinent information from the course content, apply it to a photo, and use their own voice to explain some landscape attribute they see. Students are free to explain any feature in the photo, but they must demonstrate their understanding of some geologic process previously described in class. Students are encouraged to prepare for writing by creating an observations/interpretations table, which provides structure to writing a well-organized Education Sign.

2.1 Education Signs for geologic time and slow, gradual climate change

We used the iconic sedimentary rock formations in Zion and Bryce Canyon National Parks to engage students with Earth's changing climate over geologic and more recent timescales. Composing observations and interpretations from Zion National Park was used as a more basic Education Sign activity, where students were guided to recognize the cross-bedding in the Navajo Sandstone (Figure 3) and explain the geologic process that formed it, which in turn supports an interpretation about Earth's past climate (Appendix 1). The subsequent Bryce Canyon National Park sign development is used as a more advanced activity. Applying more complex geologic interpretations, students were asked to make connections between alternating layers of different rocks of different strengths (Figure 4) with an ancient lacustrine depositional environment and distinguish this aspect from that of the role of modern climate, which explains the formation of the hoodoos (Appendix 2).

FIGURE 3 (left). **Cross-bedded sedimentary Navajo Sandstone in Zion National Park, Utah (junipers for scale). See this image used in an Education Sign Exercise in Appendix 1.** DIANE CLEMENS-KNOTT
FIGURE 4 (right). **Alternating layers of mudstone, sandstone, and conglomerate of the Claron formation in Bryce Canyon National Park, Utah (lip balm for scale). See this image used in an Education Sign Exercise in Appendix 2.** DIANE CLEMENS-KNOTT

All three of the national parks discussed thus far are located in close proximity on the Colorado Plateau and can be used together to synthesize geologic processes and natural climate change that is occurring very slowly. We created an exam question modeled after the Education Sign Exercises as follows:

> Grand Canyon, Zion, and Bryce Canyon National Parks are all located on the Colorado Plateau. Given the following ages, discuss how the climate has changed over geologic time in this region: Kaibab Formation, Grand Canyon: ~280–270 Ma; Navajo Sandstone, Zion: ~200–195 Ma; Claron Formation, Bryce Canyon: ~60–40 Ma.

This synthesis exercise could be coupled with a labeled cross-section showing the stratigraphic position of these rock formations, or could be accompanied with reminder photos the students have already seen. Our intention with this assessment was to evaluate how well our students demonstrated their understanding of natural, geologic-timescale (slow) climate change of the Colorado Plateau from the warm tropical ocean that formed the Kaibab Formation around 280 million years ago, to the dry desert 80 million years later that covered the area in sand dunes (forming the Navajo Formation), to a much wetter, lake-covered non-marine landscape nearly 150 million years later in which the Claron Formation was deposited.

2.2 Education Signs for recent-time and modern climate change

Many iconic national park landscapes were carved by glaciers during the last ice age in the Pleistocene and many of these parks today feature rapidly diminishing glaciers, snow fields, and ice caps. The next Education Sign Exercise was used to consider much more recent natural climate change, such as from the Tioga glaciation about 20,000 years ago in Yosemite National Park, California (Figure 5). For this perspective, we asked the students to take a step back from the details of the rocks themselves and look at the shape (geomorphology) of the whole landscape instead. The objective here was for students to recognize and interpret the steep, nearly vertical, walls of Yosemite Valley. Just as they had practiced earlier with the Colorado Plateau parks synthesis, students were tasked with explaining the geologic process that formed Yosemite Valley and making interpretations about Earth's past climate that supported their explanation (Appendix 3).

FIGURE 5. Yosemite National Park, California, as seen from Tunnel View. NATALIE BURSZTYN

Contrasting the enormous glaciers of the Pleistocene with the alpine glaciers still present in North America provides students with a point of view to observe and critically think about the much more rapid anthropogenic climate change happening today. Thousand-foot-thick rivers of ice that persisted for several thousand years sculpted the Earth's surface, whereas the vanishing glaciers of the last century are temporary residents of the landscape left behind by their predecessors. Because humans have been exploring and documenting North American landscapes for over a century, we have an amazing collection of before-and-after photo pairs from various national parks. This repeat photography provides visual evidence of recent dramatic change. Visually stunning "slider" images on the websites of Kenai Fjords National Park (Alaska) and Glacier National Park (Montana) document how much several park glaciers have changed in a few decades (Figure 6).

These slider photo pairs are a tool we can use for Education Sign Exercises about recent rapid climate change. Two locations that we suggest here are the Thunderbird Glacier in Glacier National Park, where the photos show the change from 1907 to 2007[4] (Figure 6), and Sunrise Glacier in Kenai Fjords National Park, showing the change from 1990 to 2020.[5] The full century between repeat photos of Thunderbird Glacier and the 40-year span between photos at Sunrise Glacier provide students with a "now you see it, now you don't" opportunity for describing observations and making interpretations related to recent climate change. The purpose of using any of these paired glacier photos is for students to recognize that what was recently ice is now rock or meadow or water, and that it vanished too quickly to be considered "natural." This is consistent with an interpretation of a rapidly warming climate due to anthropogenic causes.

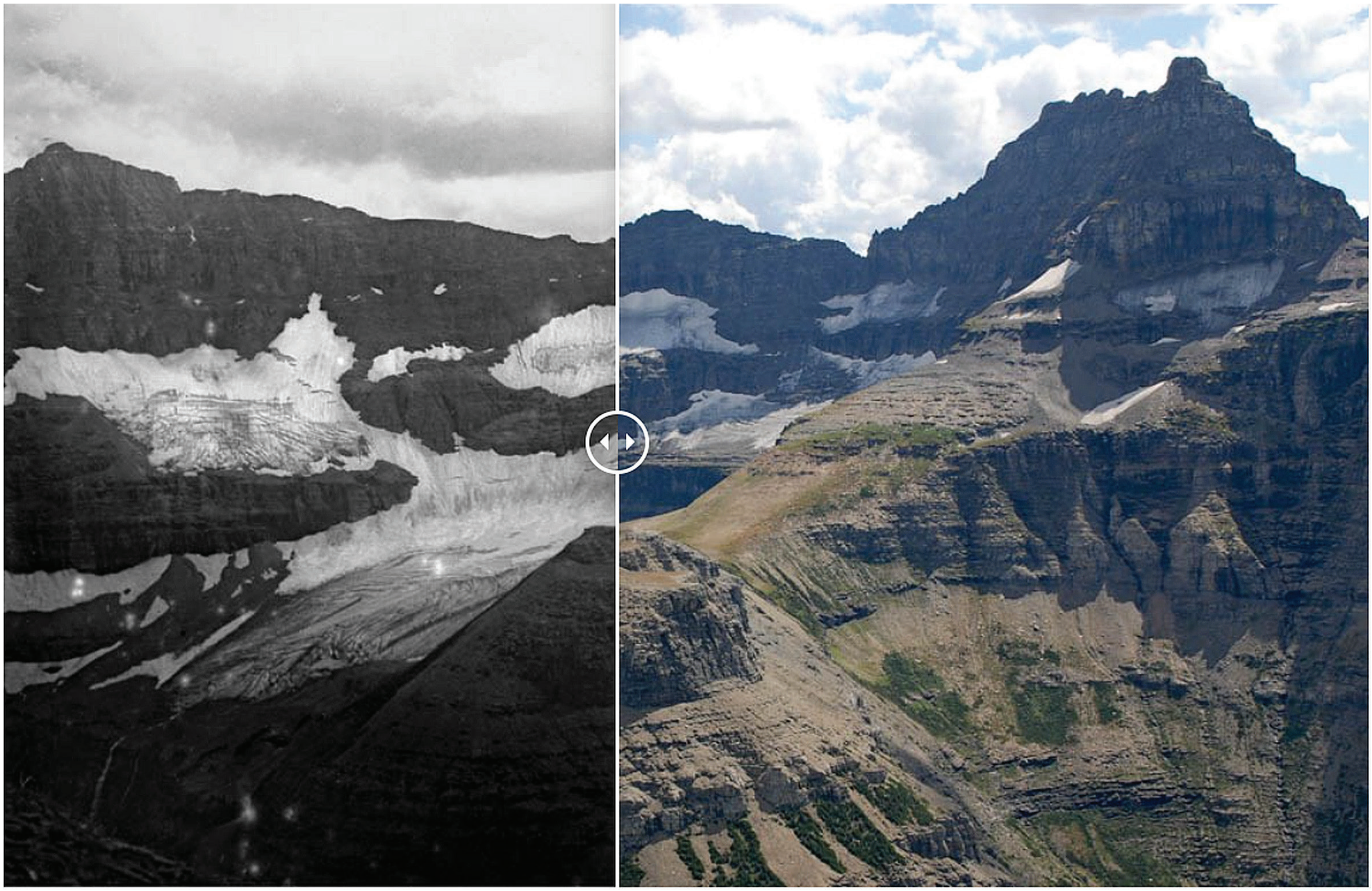

FIGURE 6. Screenshot of the slider tool for Thunderbird Glacier in Glacier National Park, Montana, from the Glacier National Park repeat photography website.

The careful timing of repeat photography of glaciers provides a concrete example of weather versus climate. As explained on the Glacier National Park Service website,[6] glaciers must be photographed at the end of the summer (late August to early September) when the annual snowfall (e.g., a product of annual weather) has melted, so that the extent of glacial ice (i.e., a product of decade-over-decade climate change) can be imaged.

An example of an Education Sign written for Thunderbird Glacier is as follows:

> M.J. Elrod photographed this glacier in 1907 when the ice filled the bowl-shaped depression, known as a cirque, in these mountains. Originally mountain glaciers like these were being documented and studied by scientists to understand more about past climates and how glaciers erode landscapes. The photo taken a century later (D. Fagre, 2007) shows only a few remnants of ice scattered in the shade of the rocky cirque cliffs and the bowl completely empty. In one hundred years the vast majority of the ice has melted away, exposing the rock beneath, and vegetation has even started to grow. Mountain glacier scenes like these are evidence of how quickly human-caused climate change is impacting our landscapes as these vanishing remnants of the last ice age are some of the most dramatic visuals of our rapidly warming climate.

ACTIVITY 3: GOOGLE EARTH ENGINE TIMELAPSE

Earth Engine, a platform for satellite data analysis created by Google, includes *Timelapse*.[7] Timelapse is a tool that shows zoomable video time lapses of our planet created with satellite images going back to 1984. This powerful tool allows anyone to access and observe how the surface of Earth's continents have changed over the past four decades. Google Earth Education describes it as "a planetary-scale platform for environmental data analysis, an invaluable tool for students to deepen their knowledge of the implications of climate change, and much more."[8] The Timelapse function is accessed from the Earth Engine homepage. Within Timelapse, a menu on the left provides a suite of curated locations depicting landscape changes that range from glacial retreat and meandering rivers to urban growth and irrigation changes to deforestation and the drying of the Aral Sea. From the search bar, users can "fly" to any location in the world and observe how it has changed since 1984. This tool is a wonderful accompaniment to the repeat photography documenting some parks and could be used as a proxy for repeat photography for parks that have not been documented.

Using the Education Sign framework from the "before and after" Thunderbird Glacier example described in the previous section, we did something similar using Timelapse. All of the US national parks can be visited via Timelapse for our students to observe and interpret impacts of anthropogenic climate change that have occurred in the last 40 years. We have found that the biggest challenge for GE students is to describe observations from the satellite images comprising the Timelapse videos, yet doing so is important for them to accomplish because these descriptions are also most telling for broadscale landscape impacts due to recent climate warming. For this final exercise, we established a new set of guidelines for making observations and interpretations from satellite imagery. We had students focus on descriptions of the changes in spatial cover as represented by colors within the image (e.g., how do the relative proportions of brown, green, white, and blue change throughout the Timelapse?). For the interpretations, two "levels" counted: (1) what is the landscape feature that is represented by the color in the image (e.g., blue = lake, white = glacier), and (2) how does the change in spatial distribution of a color over time serve as possible evidence for the impacts of a rapidly warming climate on the area (e.g., green to brown might indicate drought, brown to blue might indicate sea level rise, white to brown or blue might indicate glacier retreat).

Gates of the Arctic National Park, Alaska, and Grand Canyon National Park, Arizona, are powerful examples in two distinct geographic settings of dramatic, observable changes due to a warming climate. For example, in a Timelapse video centered on the northeast corner of Gates of the Arctic National Park one can observe the extent of ice loss in the park since 1984. Meanwhile, the Colorado River Basin has been experiencing drought for the last two decades,[9] an effect that has stark observable characteristics through satellite imagery. By choosing a frame that includes both western Grand Canyon National Park and Lake Mead just downstream, a Timelapse video reveals a substantial decrease in lake and river surface water over time. Similar to the repeat photography examples in Activity 2, the purpose in using a Timelapse video is for students to recognize that a landscape recently covered with ice, water, or vegetation now is covered differently—or even is exposed rock. Timelapse can help students visually quantify the rate of change, forming a springboard for discussion as to whether the rate is too rapid to be considered "natural," and how anthropogenic climate change may have played a role.

Here is an example of a Timelapse description written for Grand Canyon National Park:

> As the Timelapse plays, focus your attention on Grand Canyon West and South Cove. The Timelapse begins in 1984 and plays through 2020. Pause in 1984 to get your bearings. The navy blue to almost black color that is South Cove in 1984 is the eastern arm of Lake Mead. The dark color is the water in the lake. Looking east toward Grand Canyon you can follow the Colorado River by observing the navy color fade to a green ribbon in the brown surroundings. As you play through the Timelapse, watch how after the year 2000 the size of South Cove decreases and the color fades to green. At the same time, note that the green ribbon of the Colorado River vanishes into the brown of the rest of the image. What you are witnessing is the lowering water level of Lake Mead and the drying of the Colorado River over a period of only thirty-six years. How could this happen? The answer is a bit complicated, but documented factors include the warming climate and increased water demand by the [S]outhwest's growing population. This observed change occurred during a period of drought over the last two decades that generated increased evaporation, decreased winter snowpack, and diminished groundwater replenishment.

FINAL THOUGHTS

Here we have focused on using Education Signs to help our students to develop an understanding of climate change occurring at geological and historical timescales. However, we also use the Education Sign Exercises in The Geology of National Parks class as a mechanism for students to demonstrate understanding of any geologic process that can be photographed (e.g., an erupting geyser or volcano), while also developing a basic understanding of the scientific method. Depending on the instructor and the structure of the class, the Education Sign Exercises can be used as in-class activities, for homework or "lab" exercises, or on exams. With these activities we have been able to merge teaching about climate change to a general population of undergraduate students with the GE learning goals of unifying themes in science, scientific reasoning, relating science to significant social problems, and effectively communicating in writing.

The structure of the assignments we presented within our GE course, The Geology of National Parks, is adaptable for a range of class sizes and also works well online, combining scientific knowledge with effective communication. However, this opportunity is also a limitation: students do not even have to visit a national park to complete the work … but hopefully they are inspired to do so at some point!

ENDNOTES

1. California State University, Fullerton. N.d. General Education Program. https://www.fullerton.edu/general-education/
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9. NASA [National Aeronautics and Space Administration]. N.d. Earth Observatory: Lake Mead keeps dropping. https://earthobservatory.nasa.gov/images/150111/lake-mead-keeps-dropping

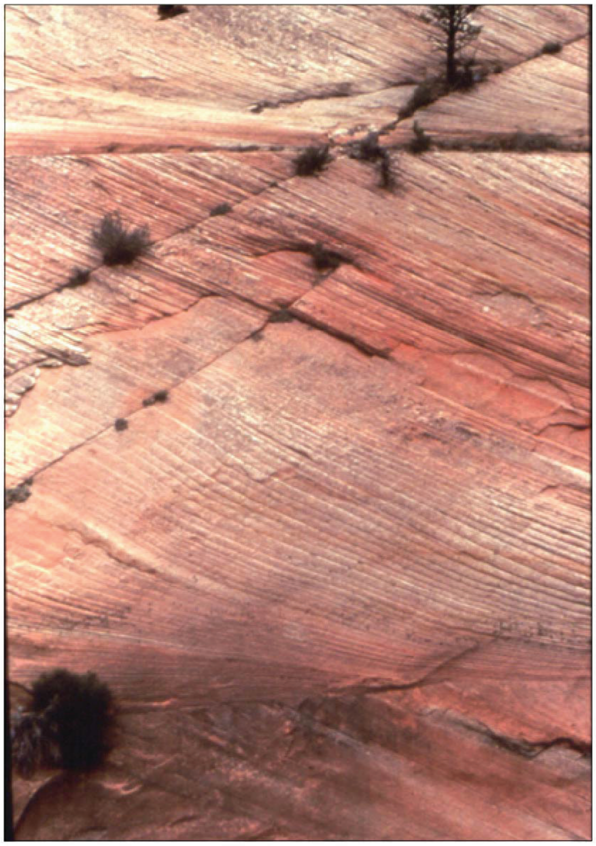
(Appendices continue below)

APPENDIX 1

Activity Guide for introductory Education Sign Exercise for Zion National Park, Utah, including prompt and (instructor-level) example write-up. PHOTOS DIANE CLEMENS-KNOTT

Write an Education Sign for these photos that encourages the visitor to observe something in the landscape, then explain how it formed. Remember that these signposts are directed to visitors with no geology training who would like to learn about what they're seeing. Structure your signpost to answer their possible questions of: "What is this?" "How did it form?" What does it tell me about how the Earth works?" And, make sure to include a 'hook' that interests the visitor enough to read through the entire sign!

Overview and close up views of Navajo Sandstone in Zion National Park (conifers for scale).



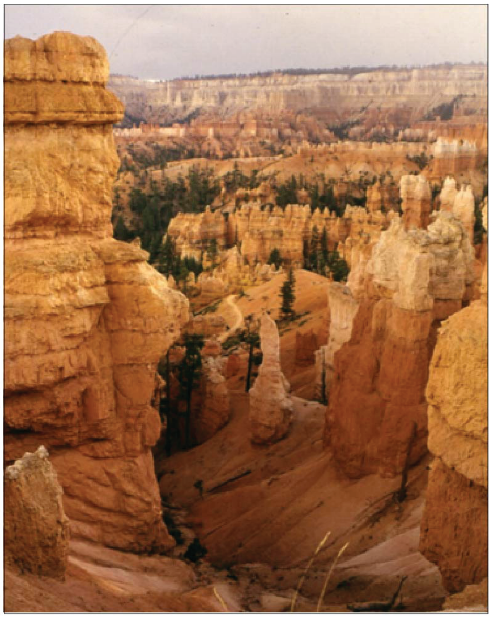
The ~2,000'-high cliffs soaring above your head are composed of the Navajo Sandstone, a ~200-million-year-old rock formation having a very interesting story to tell. Look closely to see the packages of diagonal lines dipping to the right, with each package being separated from the next by a near-horizontal line. How did these structures form? If you make repeat visits to a sand dune field, you'll realize that the sand dunes migrate across the landscape as winds change direction from season to season. Dune migration happens as blowing wind causes sand grains to saltate, or 'jump' up the back of a dune; at the dune peak, sand grains slide down the steep dune face and collect as steeply dipping sand layers. As dunes migrate across the land, they bury and plane off the tops of older dunes, creating the subhorizontal surfaces that you see separating the packages of dipping layers. Turns out these sandstone cross beds formed when a huge Sahara-type desert covered much of the western U.S., telling us that the local climate was much drier 200 million years ago.

APPENDIX 2

Activity Guide for advanced Education Sign Exercise for Bryce Canyon National Park, Utah, including prompt and (instructor-level) example write-up. PHOTOS DIANE CLEMENS-KNOTT

Write an Education Sign for these photos that encourages the visitor to observe something in the landscape, then explain how it formed. Remember that these signposts are directed to visitors with no geology training who would like to learn about what they're seeing. Structure your signpost to answer their possible questions of: "What is this?" "How did it form?" What does it tell me about how the Earth works?" And, make sure to include a 'hook' that interests the visitor enough to read through the entire sign!

Overview and close up views of Claron Formation hoodoos in Bryce National Park (lip balm for scale).



Hoodoos! The delicate rock towers of Bryce Canyon National Park

The fairyland of towers for which Bryce Canyon is famous owes its existence to a fascinating combination of modern and ancient climates. Deposited approximately 60 to 40 million years ago, relatively thin beds of mudstones, sandstones and conglomerates record sediment deposition in large lakes that were home to freshwater snails and fish. These ancient rock layers are generally soft but vary in strength, so some layers erode faster than others producing an alternation of bulging and recessed layers. This causes the hoodoo towers to bulge outwards and pinch inwards...but the ancient lake climate is only one half of the story...

Today, southwestern Utah is dominated by alternating plateaus and valleys that were formed by faulting. This faulting cracked the soft rocks of the Claron Formation, creating the vertical lines, or joints, you see in the cliffs. Rain seeps downward into these vertical cracks, and during much of the year nighttime temperatures drop below freezing. As the percolated water freezes overnight it expands, and the ice pushes the joints apart. Over time, erosion separates the hoodoo towers from the thin walls, or fins, of rock. As you might guess, because this freeze-thaw process continues throughout much of the year, the hoodoos are short-lived. Luckily, as old hoodoos are destroyed, new ones form in the recessing rock cliffs, preserving the overall fairyland of Bryce Canyon that you see before you.

APPENDIX 3

Activity Guide for Education Sign Exercise for Yosemite National Park, California, including prompt and (instructor-level) example write-up. PHOTO NATALIE BURSZTYN

Write an Education Sign for this photo that encourages the visitor to observe something in the landscape, then explain how it formed. Remember that these signposts are directed to visitors with no geology training who would like to learn about what they're seeing. Structure your signpost to answer their possible questions of: "What is this?" "How did it form?" What does it tell me about how the Earth works?" And, make sure to include a 'hook' that interests the visitor enough to read through the entire sign!

Overview of Yosemite Valley at Tunnel View.

The Legendary Tunnel View in Yosemite National Park

This is Tunnel View and we are looking northeast toward Yosemite Valley. Notice that this valley has steep, near-vertical walls, and a nearly-flat broad bottom. The shape is almost that of the capital letter U. The original "U-shaped" valley formed at the end of the Pleistocene, around 20,000 to 15,000 years ago when glacial ice deepened and widened the original V-shaped river valley. As the glacier slowly flowed under its own weight, it put lots of pressure on the surrounding valley walls for thousands of years. The sand and gravel trapped in the ice gradually eroded the rock walls by abrasion and widened the valley into the classic U-shape we see today framed by the sheer granite walls of El Capitan, Half Dome, Sentinel Rock, Cathedral Rocks, and Bridalveil Fall.

By 10,000 years ago, the massive glaciers of the last ice age were gone and life began taking over Yosemite valley: rivers ponded in the valley floor, depositing layers of mud and sand which changed the valley's glacial U-shaped profile to the modern box-shaped profile; eventually forming soils in the residual glacial sediment and then filling every niche from the foothills to the alpine. It's hard to imagine that where the meadows and river filled with hundreds of species of plants and animals are today, were beneath several hundred feet of ice a few thousand years ago!