A YOSEMITE NATIONAL PARK VIRTUAL FIELD TRIP WEBSITE FOR UNDERGRADUATE GEOSCIENCE COURSES

An Undergraduate Thesis

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Bachelor of Arts

in Earth Science

By

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Abstract

Virtual field trips are quickly becoming a new, integral part of geoscience education in the modern age. As an alternative to traditional field trips, virtual field trips can provide a cheap, effective, and engaging experience that is accessible for students, teachers, and informal audiences of all backgrounds, no matter the reason why they cannot visit the field. I have developed a free virtual field trip website for Yosemite National Park that is geared toward undergraduate geoscience courses (www.yosemitevirtualfieldtrip.net). Yosemite National Park is an exceptional location for a virtual field trip to educate about intrusive magmatic systems that were linked to volcanic eruptions in the past due to its excellent exposure of the Cretaceous, 95-85 Ma magma plumbing system called the Tuolumne Intrusive Complex (TIC). The TIC is a nested, normal zoned intrusive complex composed of three plutonic rock units that formed through incremental growth of multiple magmatic pulses that utilized the same magma pathway. Today, these rock units are represented by equigranular diorite and granodiorite to porphyritic granodiorite and granite compositions, the latter containing megacrystic K-feldspar. Additionally, the TIC exposes a significant amount of magmatic structures at the outcrop scale including dikes, enclaves, schlieren layers, and stoped blocks of the metamorphic host rock that inform about how magma systems operate at depth. After traveling to Yosemite National Park in 2019 to obtain the proper media on the TIC, the website began development on the free website builder, "Wix". The website begins by introducing the viewer to basic geologic concepts including geologic time, incremental pluton growth, the rock cycle, mineralogy, and other major concepts pertinent to introductory geology courses. As the virtual field trip progresses and a firm background of understanding of basic geology is established, the website educates

the viewer on the minerals that are seen in the equigranular diorite and granodiorite rock units in Yosemite as well the various magmatic systems that are seen in the national park with a focus on enclaves, dikes, and stoping. Various interactive strategies are implemented throughout the website including quizzes, maps, animations, lab demonstrations, and descriptive videos. The goal of this project is to not only educate the public about the geology of Yosemite National Park, but to excite and appeal to non-scientific audiences in a way that is accessible and requires critical thought, application, and understanding.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Valbone Memeti of California State University, Fullerton for her mentorship during this project. Her patience, intelligence, guidance, and utter support was pinnicle in the completion of my website and thesis. I would like to thank her husband, Dr. Scott Paterson of University of Southern California, and all of his graduate students for their support and knowledge in the field that inspired me to go above and beyond in creating my virtual field trip. I would also like to thank Dr. Sandra Zeedyk, Angela Daneshmand, and Dr. Jeffrey Knott of California State University, Fullerton, for their encouragement and support. Finally, I would like to thank my parents, siblings, and friends for allowing me to bore them with my endless ideas and test-runs for my website. I would not be anywhere without their unconditional love!

1. Introduction

Virtual field trips are quickly making their mark on modern education and are capable of radically impacting undergraduate geology courses. Professors typically teach in a lecture-based format that is best suited for the student that excels in auditory learning. However, this type of teaching strategy is not effective for students who are visual or tactile learners. The scientific field requires hands-on interaction to research and study, specifically in the geosciences. However, the reality is that professors do not have the time or resources to design interactive hands-on activities or take their students to the field when they are working in grand lecture halls. Even for classrooms with a small number of students, professors are limited in the locations that they may take their students to due to long distance from the university, safety concerns in the field, or cost limitations. Even when a field trip can be successfully planned, many students may not be able to participate in the trip due to disabilities, financial limitations, or overarching commitments--such as students who are working and/or are mothers (Atchison, Feig, & Stokes, 2011; Bursztyn, Shelton, Walker, & Pederson, 2018). Traditional field trips have their advantages, but virtual field trips provide an inexpensive, easy, efficient, and accessible alternative that allow students to observe science in the real world (Bursztyn et al., 2018). Virtual field trips allow for professors to easily implement an engaging lesson plan into their curriculum with little effort or resources that can benefit the auditory, visual, and tactile learner. Additionally, a virtual field trip enhances students' knowledge on the subject by interacting with the content and applying it to reality.

The virtual field trip designed for this thesis project focuses on the magmatic features located in Yosemite National Park. Yosemite is a profound geologic location that invites and provides many opportunities for scientific learning, specifically regarding magmatic history and features. The decision to design a virtual field trip surrounding magmatic systems was due to the lack of educational tools on the topic and the opportunity for application of the topic to greater geological concepts. Additionally, magmatic features in Yosemite are a fascinating topic that would create a gripping virtual field trip that excites students about science. The purpose of this work is to provide professors and students (with very little geologic background) with an accessible, fun educational resource that not only educates them about the magmatic features in Yosemite, but also helps to build a passion for the geosciences.

2. Background

2.1 Types of Virtual Field Trips

Many types of virtual field trips have been developed in recent years in many different formats. The results on the effectiveness of them are very promising. In 2017, Dr. Natalie Bursztyn developed a virtual field trip application on smartphones for Grand Canyon

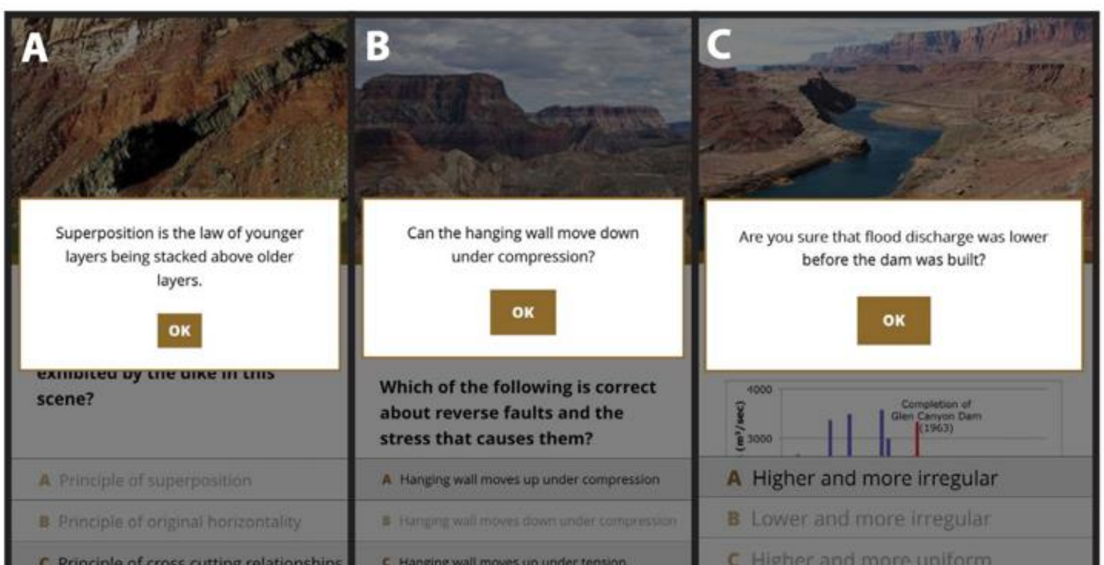

Figure 1: Grand Canyon virtual field trip application with multiple-choice questions. (Bursztyn et al., 2017)

National Park for use in introductory geology college courses (Figure 1). This field trip is "taken" on a mobile device and requires the students to physically walk to various locations on their college campus as simulated by walking through the Grand Canyon. The tour involves a series of multiple-choice questions to ensure that the students understand the content of the field trip before continuing to the next activity (Figure 1; Bursztyn, Walker, Shelton, & Pederson, 2017). College students who used this virtual field trip application in their introductory geology courses showed an increase in conceptual understanding and overall engagement across the board (Bursztyn et al., 2017). Despite the variety in post-test scores, no student was negatively impacted by the use of the virtual field trip (Bursztyn et al., 2017). While this virtual field trip was on an application for smartphones or tablets, virtual field trips can be formatted for computer websites as well.

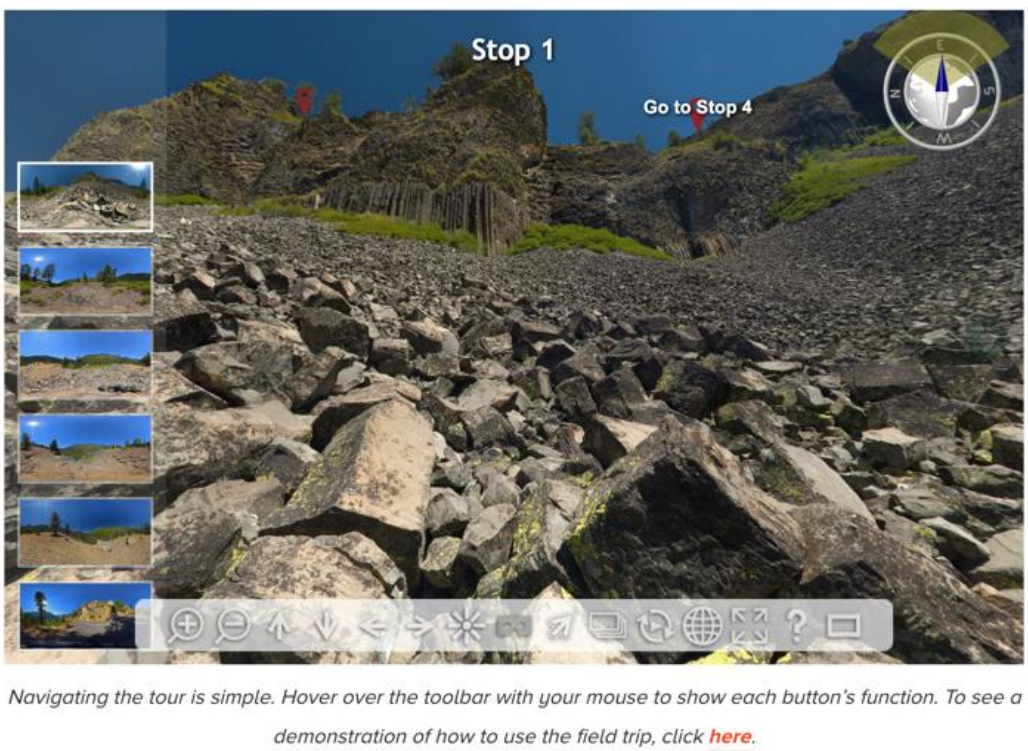

Figure 2: Columns of the Giants virtual field trip website screenshot showing the virtual feature at Stop 1. Features include a compass, a textual observation, and images (Hollister, 2016).

Figure 2 shows a virtual field trip at the Columns of the Giants in California created by Ryan Hollister on Science Friday (Hollister, 2016). This virtual field trip is a website that has stations set on a map and allows for a 3-D virtual reality experience paired with many questions to engage scientific thought. In addition to the questions, this website includes numerous illustrations, text, and images to describe the geological formations of the Column of Giants, including topics such as glaciers and igneous rock formation (Hollister, 2016). While the virtual field trip website is not as portable as a virtual field trip application, it allows for many more options for resources or features that may be included in the virtual field trip as there is more flexibility for formatting and content. A website will also give more opportunities for students to learn valuable information as it allows for a significant number of interactive features and is guaranteed to be used easily, especially for a college student aged audience. Additionally, computers are easily accessible to schools in many communities of varying economic status as they can easily be checked out on various school campuses or public libraries. Therefore, a virtual field trip website is the best way to provide an effective learning experience for a wide population.

The content of the virtual field trip involves the basic topics of igneous rock formation and classification and all preserved features that can be used as evidence for processes. Magma is molten rock that is mostly stored in the Earth's crust, unless it erupts in a volcano. When magma cools and crystallizes, igneous rocks are formed. Igneous rocks are classified based on the location of formation, composition, and texture: Igneous rocks formed in the crust at depth are called intrusive, while rocks formed from magma cooling at Earth's surface are classified as extrusive. Igneous rocks are typically composed of silicon, oxygen, iron, and magnesium, as well as many other elements as determined by their host magma and magma source. Mafic, or basaltic, igneous rocks are high in magnesium and iron and low in silica and oxygen and are dark in color. Contrastingly, felsic, or granitic, igneous rocks are high in silica and oxygen and are light in color. Igneous rocks composed of a mixture of these elements are typically considered intermediate, or dioritic and granodioritic. Igneous rocks can be coarse-grained, fine-grained, porphyritic, or glassy in texture. Coarse-grained rocks (phaneritic) are typically intrusive and have interlocking crystals visible with the naked eye formed from the slow cooling of magma. Fine-grained rocks (aphanitic) have crystals that are too small to be seen with the naked eye and commonly have vesicles, or gas bubbles, that form from the rapid cooling of magma as extrusive rocks. Porphyritic rocks have a combination of fine-grained and coarse-grained crystals that form when magma crystallization begins within the Earth's crust and then is extruded to the surface and cooled quickly. Finally, glassy rocks form when lava cools so quickly that crystals cannot form a structure. The process of the cooling and crystallization of magma is a significant part of the rock cycle and has a major influence on the processes that are changing the Earth. One of the most representative locations for especially intrusive igneous rock formation of various textures and compositions is in Yosemite National Park (Tarbuck & Lutgens, 2009).

2.2 Geology of Yosemite National Park

Yosemite National Park is part of the Sierra Nevada, located in eastern California, that formed from the uplift and tilting of continental crust (Figure 3; Huber et al., 1989).

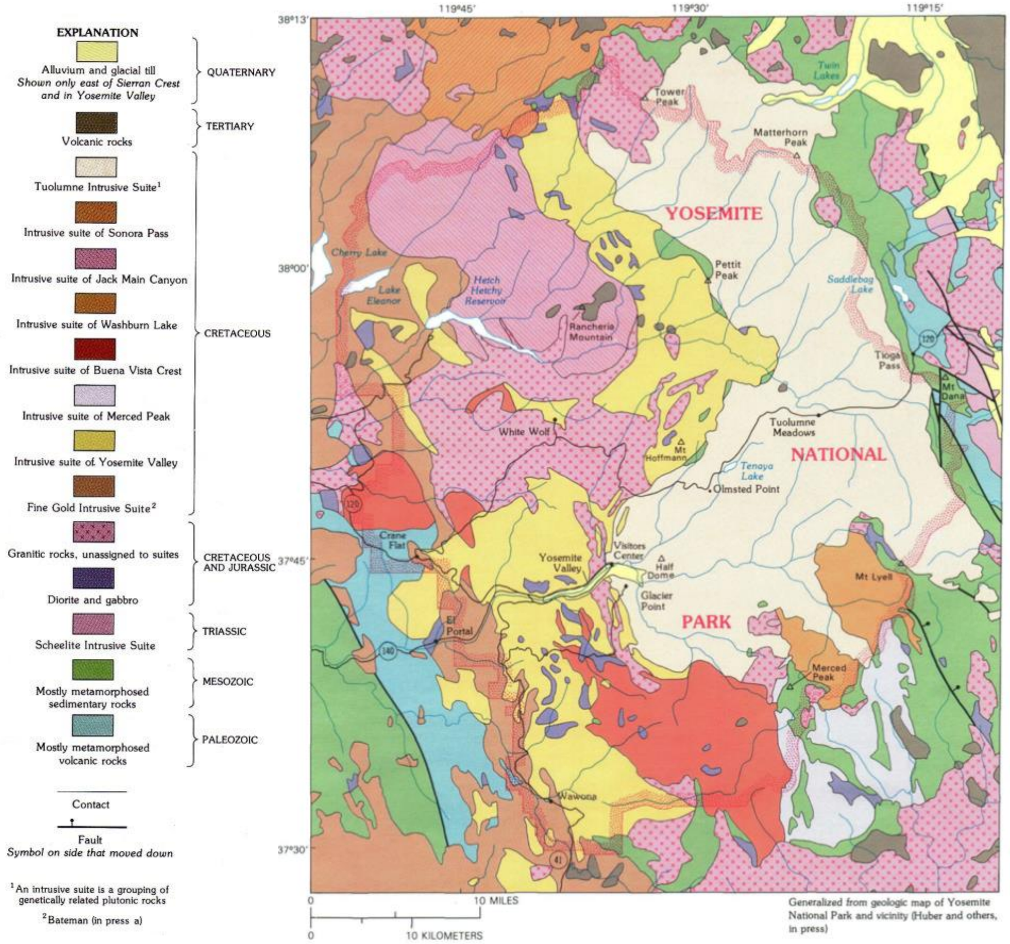

Figure 3: A generalized geologic map of Yosemite National Park after Huber et al. (1989).

Yosemite National Park is known for its profound amount of granodiorite and granite that comprise the vast majority of the exposed rock in the park. These granitoids formed from the solidification of intruded magma deep in the Earth’s crust during the Mesozoic period, and then were exposed at the surface due to uplift and erosion, including Cenozoic glaciations (Huber et al., 1989). Granitoids are a very durable rock and can withstand massive amounts of weathering and erosion to create fascinating geomorphological features such as Half Dome. The main minerals found in the granitic rocks are quartz, biotite, hornblende, titanite, potassium feldspar, and plagioclase (Huber et al., 1989). The different proportions of these minerals define the names diorite, granodiorite, and granite, all of which are observed in the so-called Tuolumne Intrusive Complex (TIC), which is located in Yosemite National Park and crystallized during the Cretaceous period (Memeti, Paterson, & Mundil, 2014).

The TIC is an accumulation of different magma units that formed plutons, i.e. large bodies of intrusive rocks, 95-85 Ma (Memeti et al., 2014). These plutons intruded at 8-10 km depth (Ague and Brimhall, 1988). The TIC shows a normal zonation, meaning that the older border of the complex is more mafic (the Kuna Crest unit) and becomes more felsic (the Cathedral Peak unit) as it reaches the younger center (Figure 4). These units intruded as new magma increments, yielding

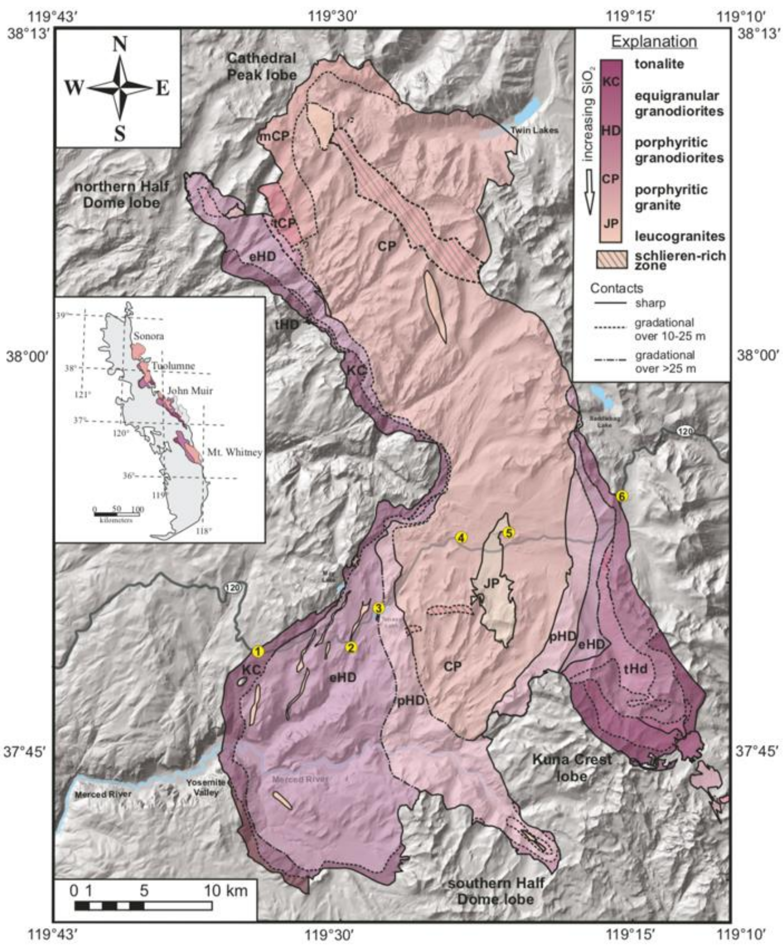

Figure 4: A map of the Tuolumne Intrusive Complex in Yosemite National Park. Dark pink represents the more mafic rock units (Kuna Crest) and light pink represents the more felsic rock units (Cathedral Peak) and depicts a normal zonation (Memeti et al., 2014).

gradational to sharp contacts between the units. The TIC rock units have unique characteristics: The Kuna Crest, as shown in Figure 5a, crystallized 95 to 93 Ma and is primarily composed of medium-grained granodiorite and diorites (Memeti et al., 2014). The Half Dome pluton intruded into the Kuna Crest to form granodiorites that are both equigranular and porphyritic and crystallized at approximately 92 to 88 Ma (Figure 5b; Memeti et al., 2014). At 88-85 Ma, the Cathedral Peak pluton (Figure 5c) intruded into the

Figures 5a, 5b, & 5c: (left to right) Kuna Crest (a), Half Dome (b), and Cathedral Peak (c) rock units (Pers. Comm., March, 2019).

Half Dome unit to cool and form porphyritic, medium-grained granodiorite before erosion and uplift exposed the TIC to the surface (Memeti et al., 2014). Due to the unique interaction between these different magmas, many magmatic structures can be observed in the TIC, especially along unit contacts: dikes, enclaves and stoped blocks are present (Paterson, 2009). They will be further defined and their formation explained and discussed in the virtual field trip.

3. Methods

3.1 Field Work

Relevant media was collected during a trip to Yosemite National Park in August of 2019. The trip was one week in length spanning from August 1st to August 6th. The trip was attended by ten people including Dr. Valbone Memeti of California State University, Fullerton and Dr. Scott Paterson of University of Southern California. Other people on the trip included geology graduate students and international students. Hikes were taken to various locations in the park including May Lake, Yosemite Valley, and Glacier Point. Photos and videos were taken of magmatic features, rock units, and scenery taken using a Sony RX10 IV provided by Dr. Valbone Memeti. Information was recorded in a field notebook detailing the date, observations of the location, and information presented by Dr. Memeti and Dr. Paterson in the field. GPS coordinates were collected using an iPhone 8 Plus and Google Earth and recorded for each image taken in the field. These coordinates were placed on each image on the website.

3.2 Website Development

Website development occurred on the free website building software entitled *Wix.* Images and videos captured during the Yosemite trip were considered for inclusion into the website. Topics to include in the virtual field trip were discussed and consist of: geologic time, incremental growth, glacial erosion/uplift, mineralogy, and magmatic features (dikes, enclaves, and stoped blocks). *Adobe Photoshop CC 2019* was utilized for the development of various image graphics to symbolize relevant geologic topics and was illustrated using a *Wacom Intuos* pen tablet. Videos were edited via *Adobe Premiere Pro CC 2019,* where audio and closed captions were added. An experiment was performed at a home laboratory using water and oil to visualize the formation of enclaves. Additional filming and audio recordings for the experiment were performed on an iPhone 7 Plus and Macbook Pro. The website has been published through the *Wix* development site with the domain name yosemitevirtualfieldtrip.net purchased through the company, *Namecheap.*

4. Website Content

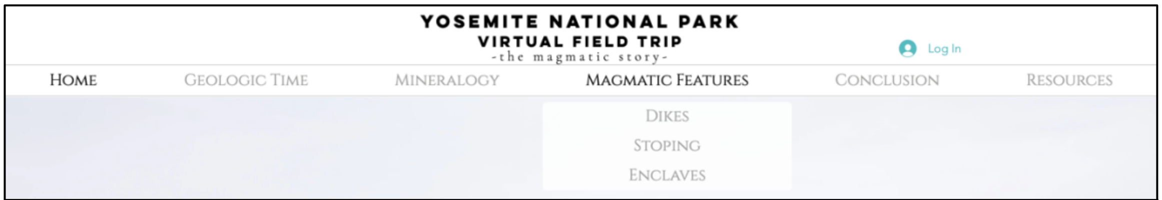

Figure 6: Yosemite Virtual Field Trip title and menu selection.

The virtual field trip website is organized in six major sections: *Home, Geologic Time, Mineralogy, Magmatic Features, Conclusion*, and *Resources*. The Magmatic Features section includes three subsections: *Dikes, Stoping*, and *Enclaves*. The website features a header, shown in Figure 6, that includes the title of the website, *Yosemite National Park Virtual Field Trip: The Magmatic Story*. Additionally, the header includes a menu featuring links to the six sections of the field trip. A footer is also included on the website that includes contact information, brief acknowledgements, and a submission form that viewers may use to send a message directly to the website author (Figure 7).

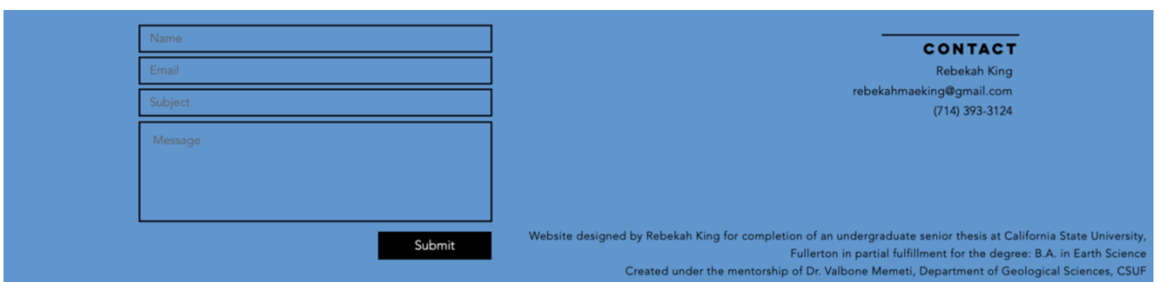

Figure 7: Footer included on the website. Includes contact information, acknowledgements, and a submission form.

4.1 Home

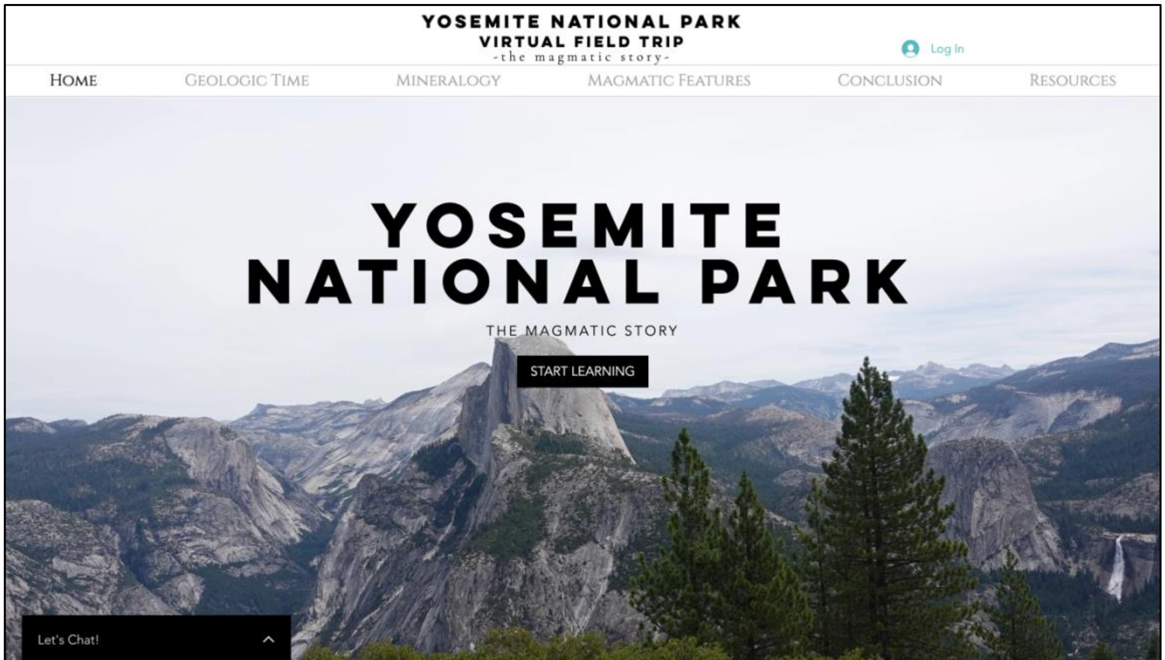

Figure 8: Yosemite Virtual Field Trip home page (yosemitevirtualfieldtrip.net).

The virtual field trip website opens with the first section entitled, *Home*. The page features the title of the virtual field trip with Half Dome as the background image (Figure 8). A button labeled, *Start Learning*, is featured on the page that navigates the viewer to the introduction of the field trip (Figure 8).

YOSEMITE NATIONAL PARK: A VIRTUAL FIELD TRIP

No money, planning, or travel required. Enjoy the beauty of one of the world's most beautiful parks from anywhere-- all you need is a computer! Gain some knowledge about the incredible magmatic history, mineralogy, and magmatic features at Yosemite that will impress your friends, family, and even professors.

Why a virtual field trip? The world has so many incredible locations that offer us life-changing experiences and knowledge. However, oftentimes it is difficult to travel to those locations due to money, time, or ability. Thankfully, current technology allows us to bring those locations to you! The purpose of this virtual field trip is to offer a free educational experience that is available for everyone!

Q&A

What will I learn?

This virtual field trip will take you through three main sections: Geologic Time/Yosemite's History, Mineralogy, and Magmatic Features (dikes, enclaves, and stoped blocks). Using videos, images, and various interactive features, you will learn about Yosemite's formation through incremental growth, determine the type of rock that Yosemite is known for by studying minerals, and understand how the processes behind magmatic features seen at the park.

Do I need to have any existing knowledge?

No! This virtual field trip is designed at the level of an introductory geology course for undergraduates. However, anyone is more than welcome to learn and there are no prerequisites!

How long will this take me to complete?

Figure 9: Yosemite Virtual Field Trip introduction and Q&A (yosemitevirtualfieldtrip.net).

The introduction of the website, shown in Figure 9, includes text that describes the purpose of the virtual field trip and features a Q&A portion to give more information about the website. The questions include: “What will I learn?”, “Do I need to have any previous geology knowledge?”, “How long will this take me to complete?”, “Can I use this field trip in my classroom?”, and “How can I get more information?” The introduction concludes with a video that features a panoramic video shot of Yosemite National Park with the message, “Welcome to Yosemite National Park!” A button labeled, *begin* redirects viewers to the next section of the virtual field trip website, *Geologic Time & Yosemite’s History* (Figure 10).

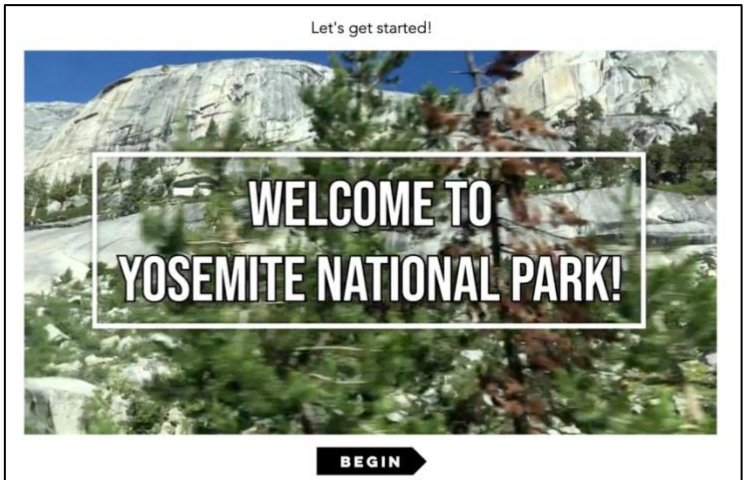

Figure 10: Yosemite Virtual Field Trip welcome video and navigation button (yosemitevirtualfieldtrip.net).

4.2 Geologic Time & Yosemite’s History

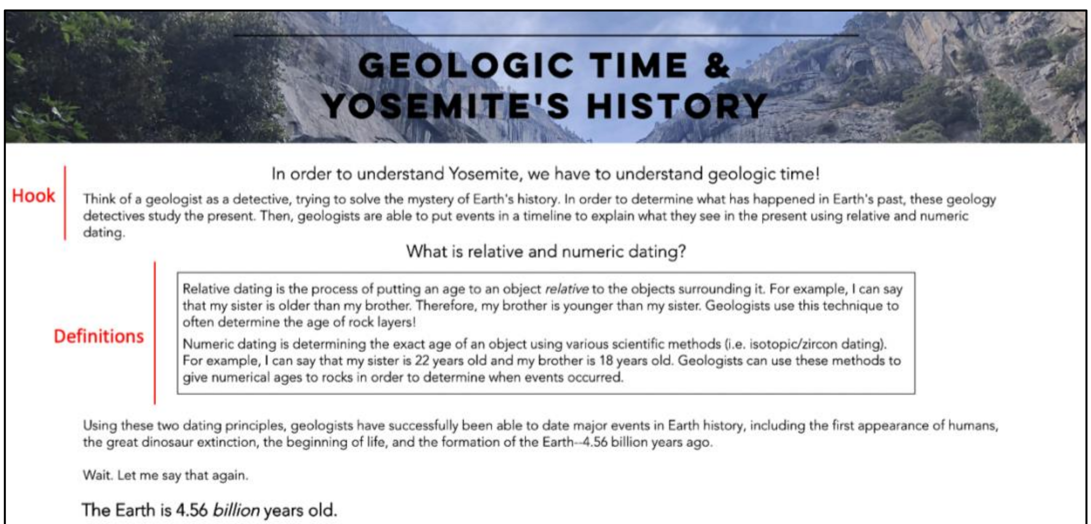

Figure 11: Yosemite Virtual Field Trip Geologic Time & Yosemite’s History introductory page (yosemitevirtualfieldtrip.net/geologic-time).

The section, *Geologic Time & Yosemite's History* begins with a hook and is followed by brief definitions of relative and numeric dating, including examples of those terms when compared to siblings (Figure 11). Then, the age of the Earth is stated.

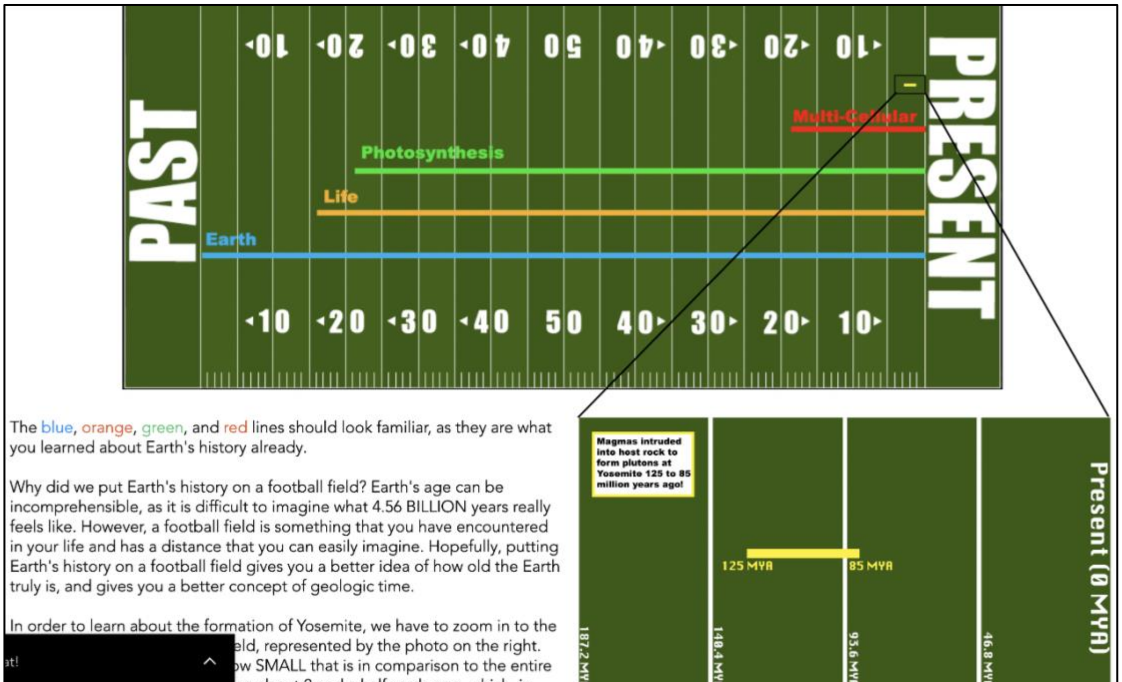

Figure 12: Football field graphic image analogue model with "zoomed in" image of the timeline of Yosemite's formation (yosemitevirtualfieldtrip.net/geologic-time).

A football field graphic image, as seen in Figure 12, is used as an analogue model of Earth's history with a focus on the beginning of life (coded with an orange line), photosynthesis (coded with a green line), multicellular organisms (coded with a red line), and Yosemite's formation (coded with a yellow line). In this analogue model, the end zones are labeled as either "past" or "present" with each inch representing 1.3 million years (Figure 12). The website "zooms in" to the yellow line on the football field representing Yosemite's formation. This "zoomed in" image is labeled with time stamps representing each yard line and the beginning and end of Yosemite's formation in millions of years (Figure 12). The website addresses the scale of Yosemite's formation when compared to the scale of Earth's history. Then, the website begins describing the process of how Yosemite formed through incremental magmatic growth (Figure 13). Incremental growth is illustrated on the virtual field trip using a five-step cartoon depicting the intrusion and cooling of magma in Earth's crust. Each step of the process is described on the website using text. This section of the website concludes with a brief description of uplift and erosion and a photo of Yosemite Valley. A button labeled *CONTINUE* directs the viewer to the next section of the virtual field trip: *Mineralogy*.

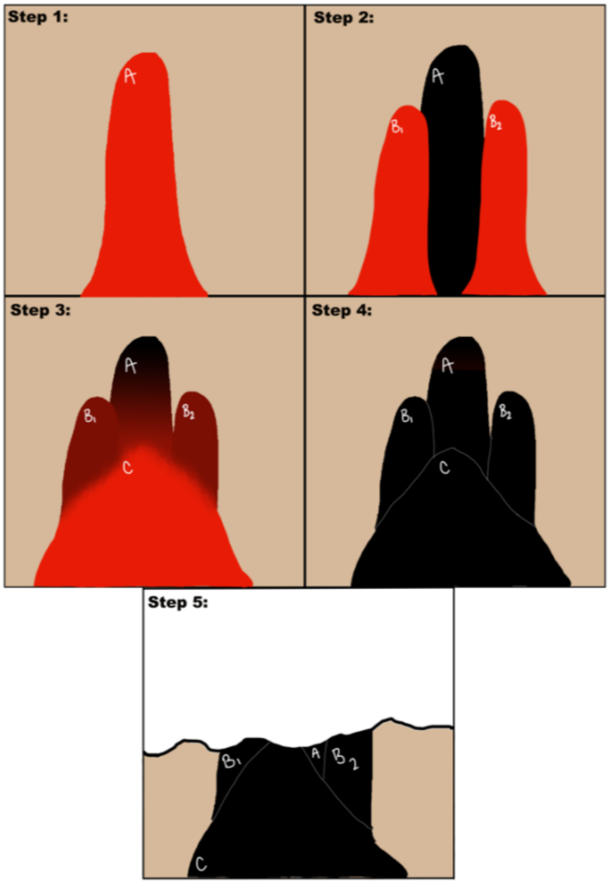

Figure 13: A cartoon depicting incremental magmatic growth. Tan represents older host rock to which magma intruded, red represents magma, and black represents hardened magma.

4.3 Mineralogy

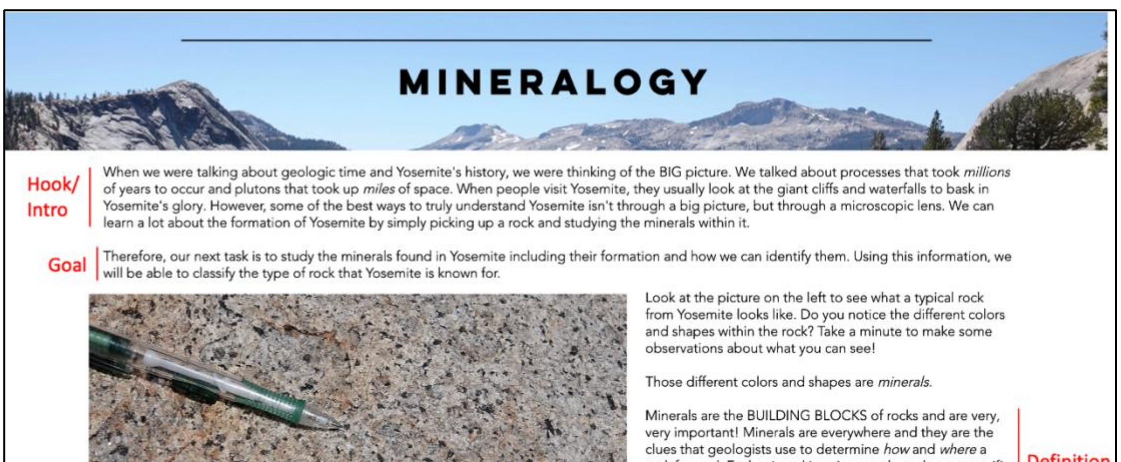

Figure 14: Yosemite Virtual Field Trip Mineralogy introduction including Hook, Goal, and Definition (yosemitevirtualfieldtrip.net/mineralogy).

The section *Mineralogy* begins with a hook that introduces the viewer to the next portion of the field trip as well as describes the goal of the section: to study the minerals of Yosemite National Park so that they can classify the type of rock Yosemite is known for (Figure 14). The website includes an image of a rock from the Kuna Crest unit in the

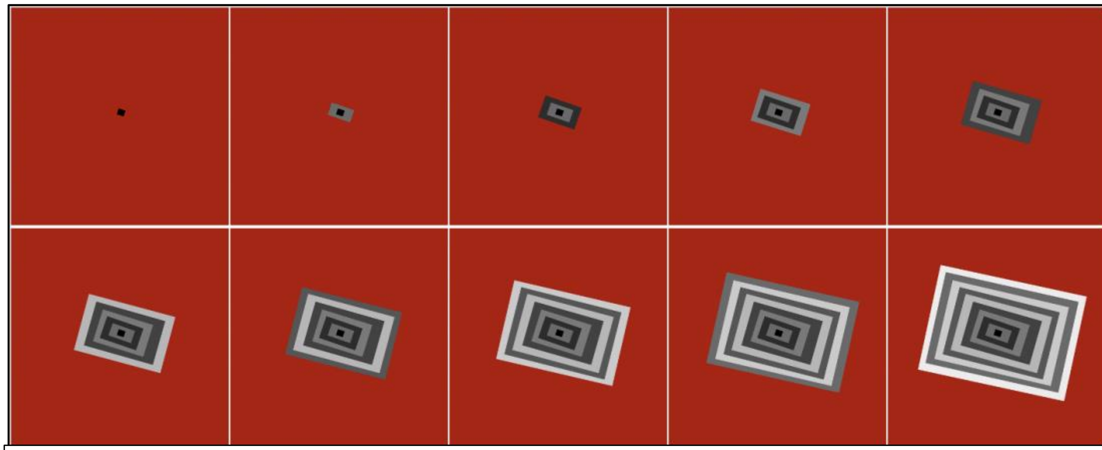

Figure 15: Mineral crystallization snapshot (order: top left to bottom right). Red represents magma, monochrome rectangles represent the mineral's layer-by-layer growth over time, preserving information about the magma environment they crystallized in.

Tuolumne Intrusive Complex. The website prompts the student to make observations of the rock followed by an introduction to minerals (Figure 14). An aminated video depicting mineral crystallization in magma automatically plays on the website as the text further describes the definition of a mineral. Figure 15 depicts the sequence of images that

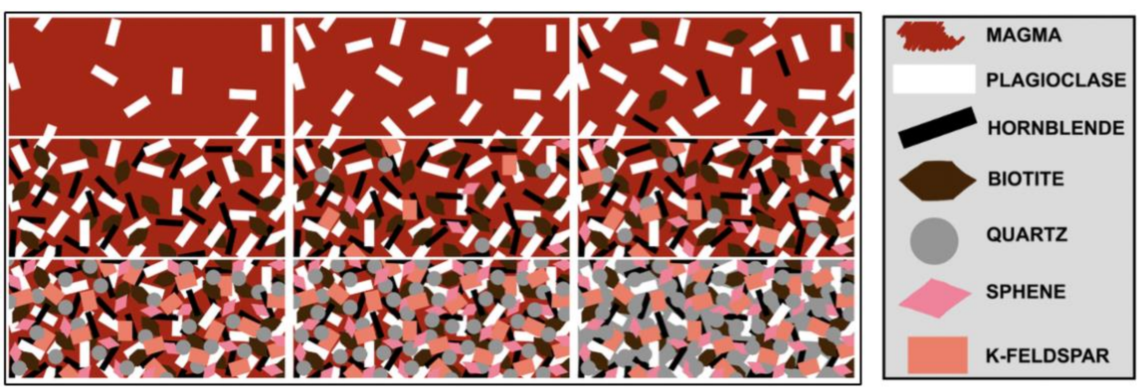

Figure 16: Yosemite mineral crystallization snapshot (order: top left to bottom right). A legend identifying the various shapes to the represented mineral is pictured on the right.

compose this animation. Next, the website introduces six minerals that are found in Yosemite: plagioclase, hornblende, biotite, quartz, sphene, and K-feldspar. An additional animated video automatically plays depicting the growth of these six minerals in magma, as shown in Figure 16. Then, the minerals are shown individually and are organized by their felsic or mafic compositions (Figure 17). The website describes how these classifications determine whether a rock is considered felsic, mafic, or intermediate and prompts the viewer to classify the image of the rock that was shown at the beginning of the page (Figure 18). There are three buttons labeled *Felsic*, *Intermediate*, and *Mafic* that the viewer can select to determine what they believe that rock should be classified as. Upon clicking a button, a lightbox appears on the screen informing the reader if they are correct or if they should try again

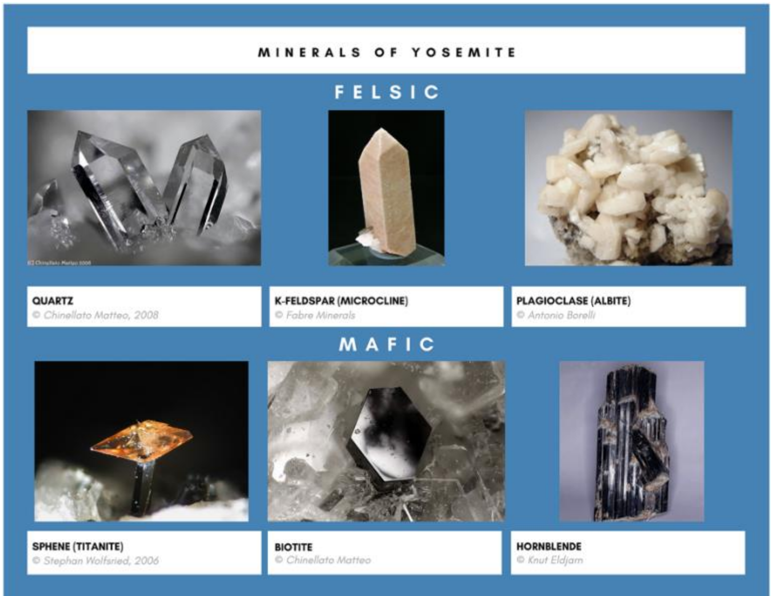

Figure 17: Mineral identification chart with images of the six individual minerals in Yosemite classified as either felsic or mafic.

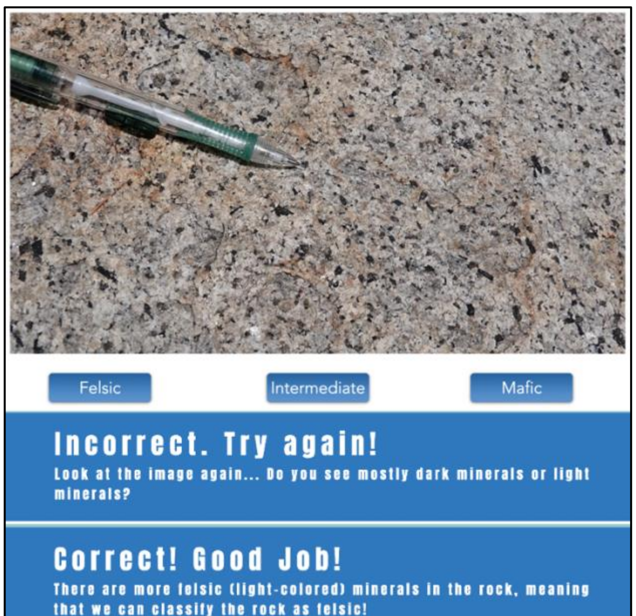

Figure 18: Rock classification question with three answers as buttons and lightboxes (yosemitevirtualfieldtrip.net/mineralogy)

(Figure 18). The button *Felsic* prompts the correct lightbox, while the buttons *Intermediate* and *Mafic* prompt the incorrect lightboxes with a hint included (Figure 18).

Figure 19: Images of two rock units in Yosemite: The website prompts the user to make observations and comparisons.

The virtual field trip then takes the viewer on a virtual "hike" using images of scenery from Yosemite National Park for the purpose of finding more rock units to observe. A new image of a rock unit is shown on the website in a slideshow followed by the same image of a rock shown at the beginning of this section (Figure 19). The slideshow automatically switches between images and prompts the viewer to make observations comparing the two different rocks. Finally, this section concludes by stating that the type of rock that Yosemite is known for is a granodiorite. A button labeled *CONTINUE* takes the viewer to the next portion of the virtual field trip: *Magmatic Features: Dikes.*

4.4 Magmatic Features: Dikes

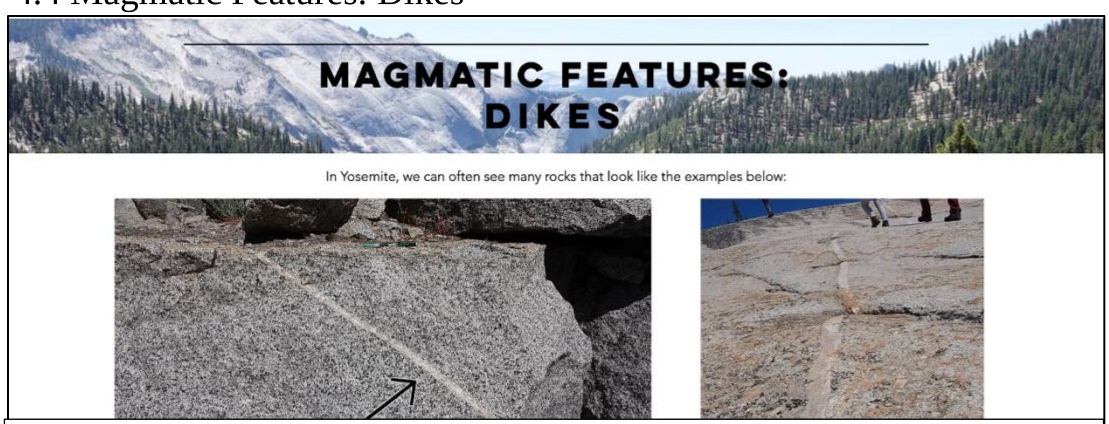

Figure 20: Yosemite Virtual Field Trip Magmatic Features: Dikes introduction (yosemitevirtualfieldtrip.net/dikes)

The section *Magmatic Features: Dikes* begins with images of dikes seen in rocks from Yosemite (Figure 20). Black arrows appear on the photos upon arrival to the page that points the viewer to observe the dikes (Figure 20). Then, the website prompts the viewer

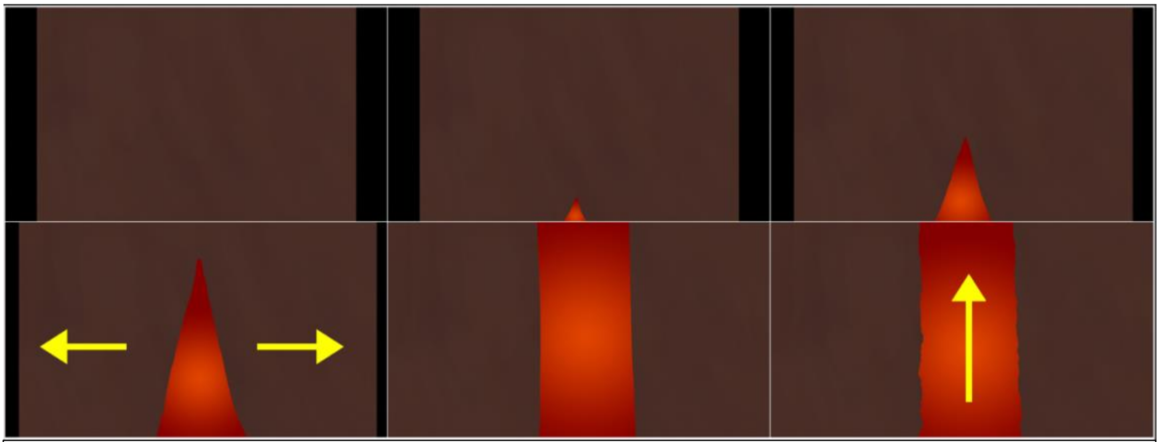

Figure 21: Screen captures of graphic images depicting the formation of dikes (top left to bottom right).

to watch a video regarding the definition and formation of dikes. The video includes six graphic images that play in sequence with audio describing the process of dike formation (Figure 21). Subtitles and yellow arrows are included as visual aids to reflect the audio of the video. An additional video, as shown in Figure 22, depicts an analogue model of magma

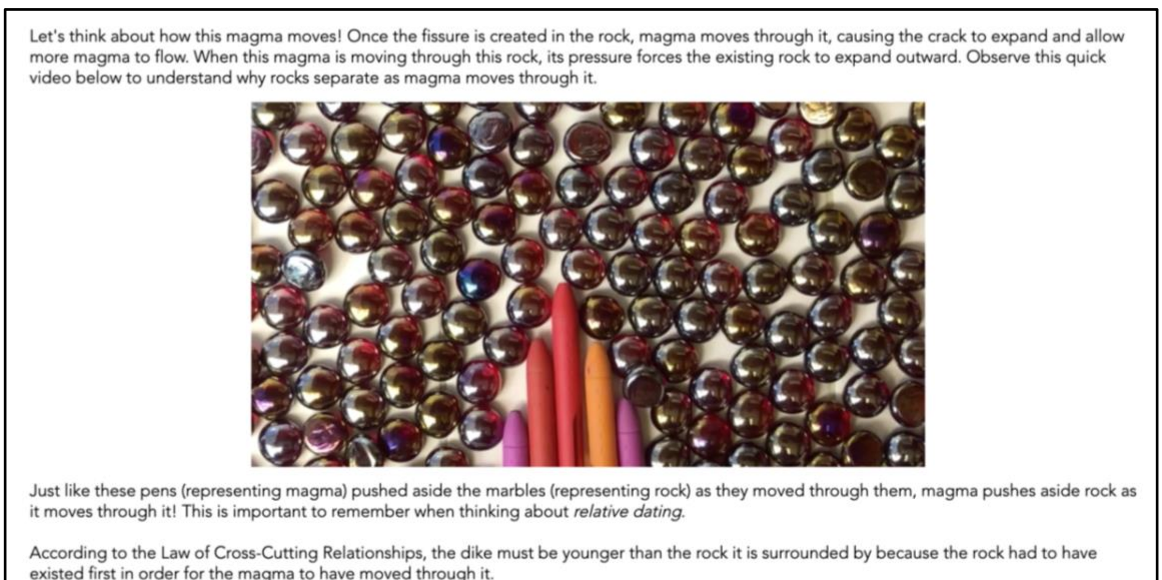

Figure 22: Screen capture of website showing analogue model of magma propagating through rock using pens and marbles.

propagating through rock using pens and marbles. The purpose of this video is to illustrate the translation of host rock when magma moves through it as well as help the viewer understand Steno's Law of Cross-Cutting Relationships. The next portion of the virtual field trip shows the viewer images of various magmatic dikes while describing that "dikes can come in many shapes and sizes". The virtual field trip continues with an assessment. The first assessment question prompts the reader to identify the dike from an image. A hover box is used that labels the dike once the viewer rolls their cursor over the image (Figure 23). The final question of the assessment asks the reader to apply relative dating, specifically the Law of Cross-Cutting Relationships. Two buttons labeled *Younger* and *Older* represent the answer choices for the question. Upon selection, lightboxes appear on the website indicating a correct or incorrect answer, as shown in Figure 24. The lightbox indicating an

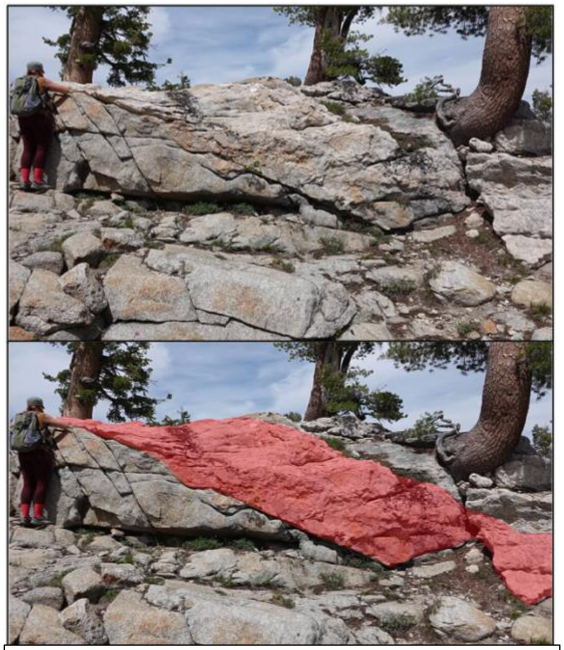

Figure 23: Two images of a dike from Yosemite that depict the hover box used as an assessment tool in the virtual field trip.

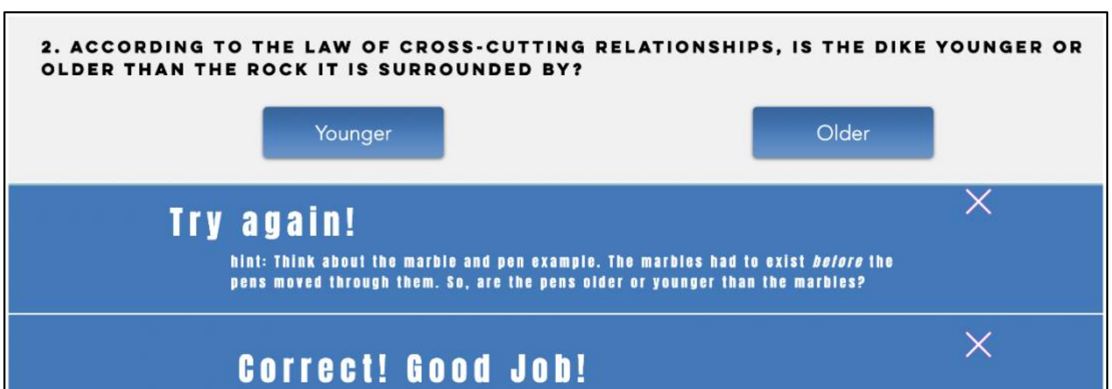

Figure 24: Assessment question featuring the two answer options as buttons and the lightboxes that appear upon answering.

incorrect answer includes a hint to encourage the viewer to try again. Finally, the section concludes with a button labeled *CONTINUE* that directs the user to the next section: *Magmatic Features: Stoping.*

4.5 Magmatic Features: Stoping

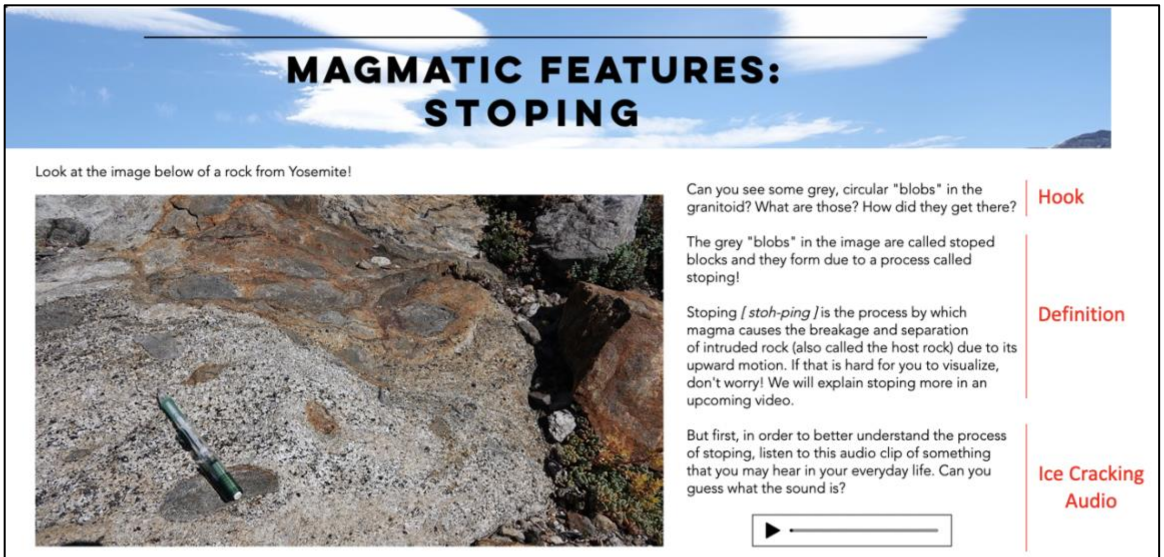

Figure 25: Yosemite National Park Magmatic Features: Stoping introduction page including Hook, Definition, and audio of ice cracking (yosemitevirtualfieldtrip.net/stoping).

The section *Magmatic Features: Stoping* begins with introductory questions about an image of stoped blocks from Yosemite followed by a definition of stoping (Figure 25). To introduce the section and act as an interactive activity, an audio clip of ice cracking is included on the page. The viewer must guess what sound the audio clip is making and select an arrow on a slide show to reveal the correct answer (Figure 26). The following

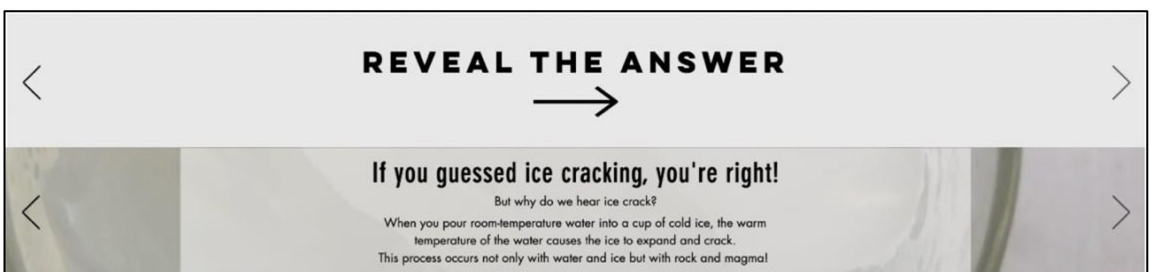

Figure 26: Slideshow that reveals the answer of the "ice cracking" audio clip and gives an explanation as to why ice cracking occurs.

slide reveals the answer to be "ice cracking" and gives an explanation as to why this process occurs (Figure 26). Then, the virtual field trip prompts the viewer to watch a video

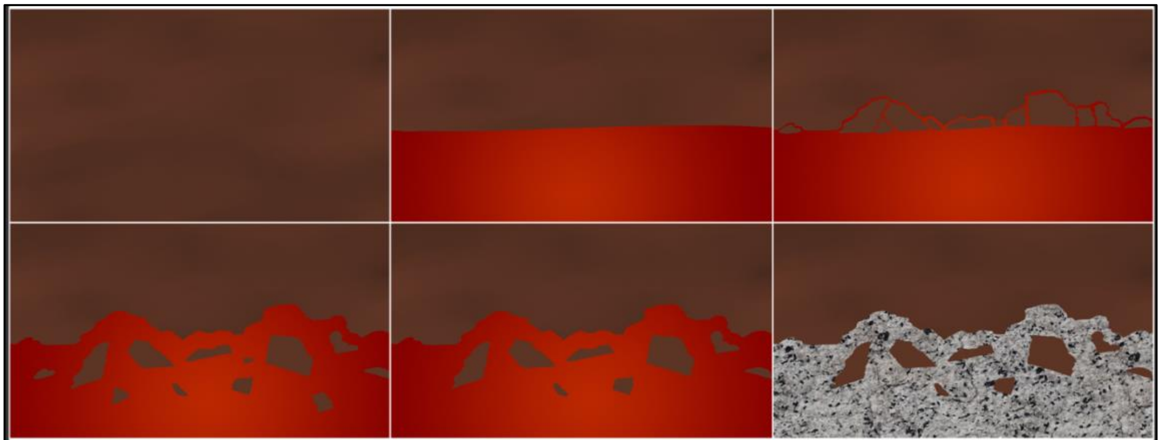

Figure 27: Screen captures of graphic images depicting the process of stoping (top left to bottom right).

regarding the process of stoping. The video includes six graphic images that play in sequence illustrating magma intrusion, the cracking of host rock, and the preservation of stoped blocks in the granitoid (Figure 27). Subtitles are included as visual aids to add to

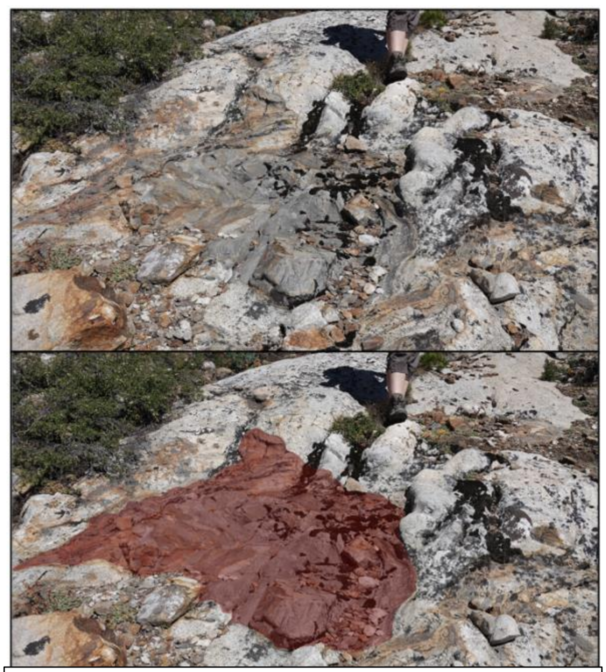

Figure 28: Two images of a stoped block used in a hover box on the website.

the audio and images included in the video. The website then connects the topics discussed in the video to Steno's 'Principle of Inclusions' using text. The virtual field trip then takes the user on a virtual "tour" for the purpose of locating more stoped blocks, depicted with images of Yosemite's trails and scenery. A hover box is used to show a stoped block on an image with a red, transparent color that activates upon the user scrolling over the image (Figure 28). The website continues to show images of stoped blocks, describing their variation in size.

The virtual field trip continues with an assessment. Two questions are used to check for the viewer's understanding of the section. Two buttons representing the answer choices appear under each question that show lightboxes when selected informing the user if they

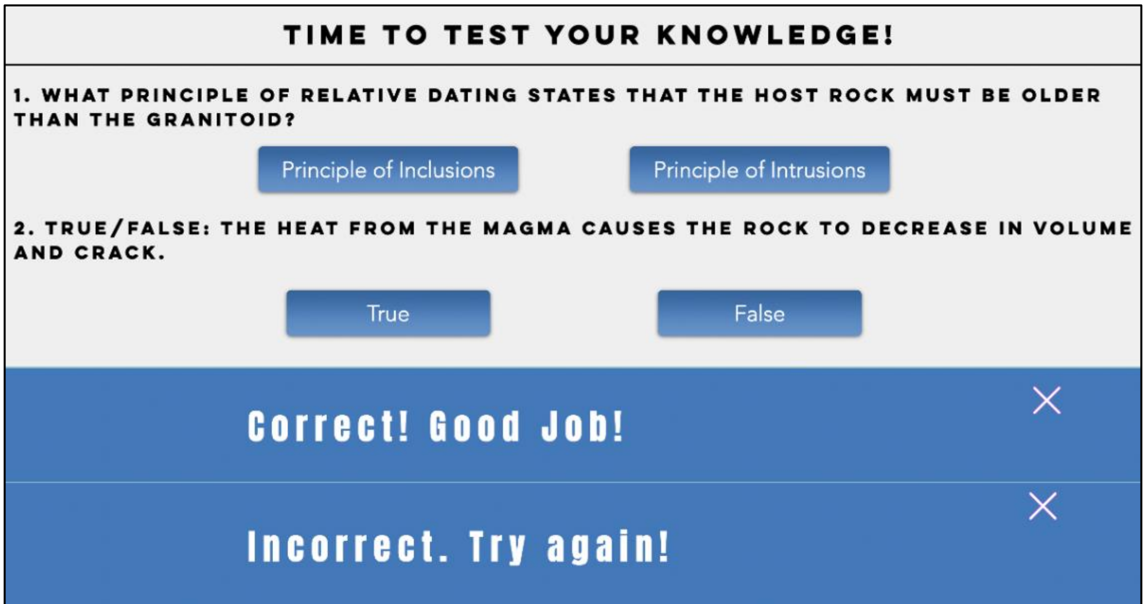

Figure 29: Assessment questions, answer choices, and lightboxes. Question 1 correct answer: Principle of Inclusions. Question 2 correct answer: False.

were correct or incorrect (Figure 29). Finally, the section concludes with a button labeled *CONTINUE* that direct the user to the next section of the virtual field trip: *Magmatic Features: Enclaves.*

4.6 Magmatic Features: Enclaves

Figure 30: Yosemite National Park Magmatic Features: Enclaves introduction page including Hook, Definition, and enclaves image (yosemitevirtualfieldtrip.net/enclaves).

The section *Magmatic Features: Enclaves* begins with a hook followed by a definition of enclaves that reference an image of the magmatic features in Yosemite (Figure 30). The virtual field trip uses a virtual lab activity, as shown in Figure 31, using oil and water to

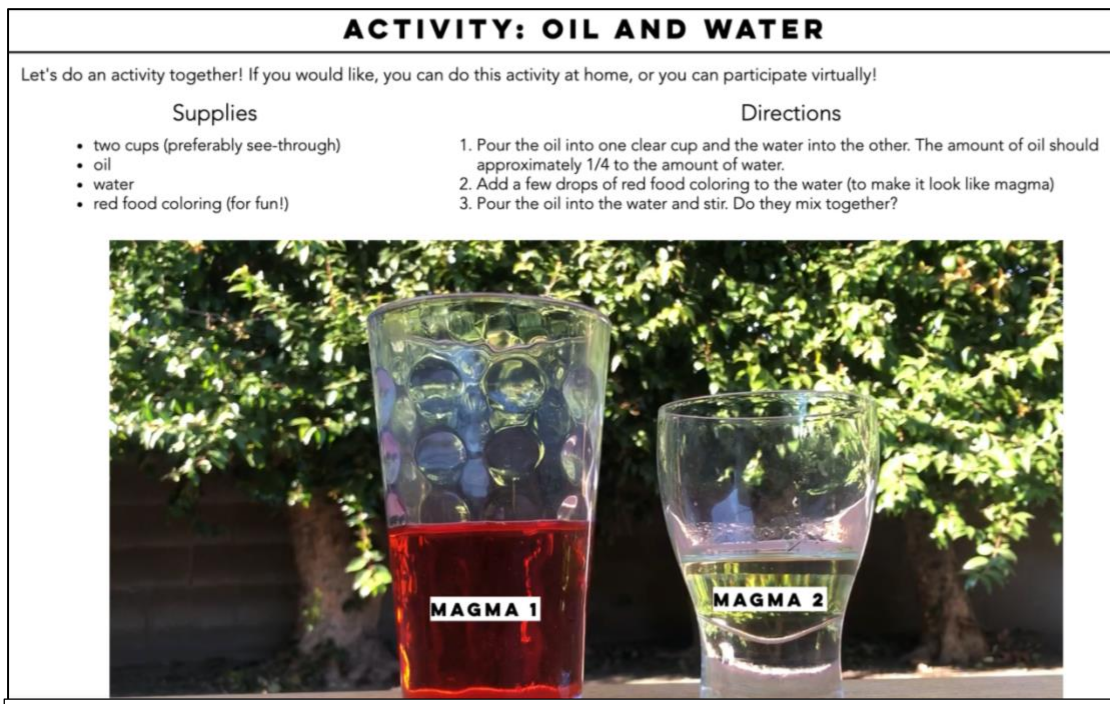

Figure 31: Oil and water activity explaining magma mingling to form enclaves, including supplies and directions.

illustrate the process of enclave formation. The supplies and directions that are needed for the activity are described so that the user may perform the activity at home, if desired. The activity is presented in a video showing the mixture of oil and water to represent the incomplete mixing of two different magma bodies. The website describes the concept of viscosity and relates it to felsic and mafic compositions. The user may select a button labeled *need a refresher on the terms felsic and mafic?* to open a box that provides a brief explanation of those terms (Figure 32). Then, the virtual field trip shows an image of the oil mixing with water next to an image of enclaves and prompts the user to compare the two images (Figure 33).

Figure 32: Pop-up box explaining the definitions of felsic and mafic minerals and their application to viscosity.

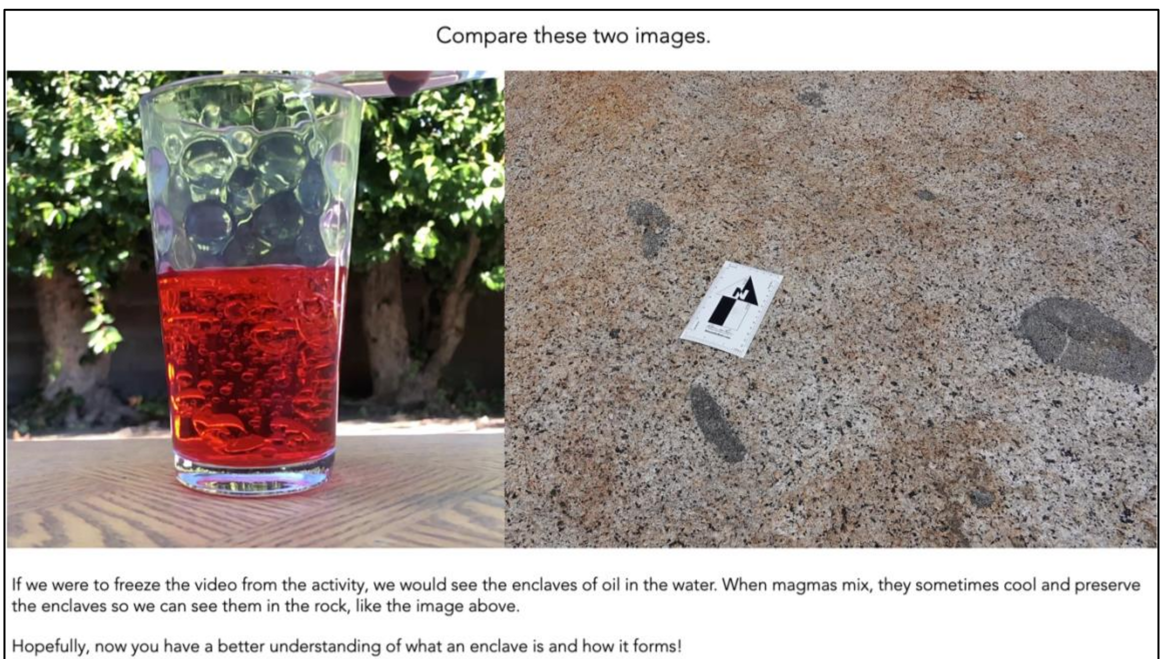

Figure 33: Image of oil and red water mixing compared to an image of enclaves in the field as seen on the virtual field trip website.

The virtual field trip continues with an assessment, as seen in Figure 34. Two questions are used to check for the viewer's understanding of enclaves. One question includes a fill-in-the-black with three answer choices. The second question requires a true or false answer. Lightboxes appear upon selection of answers that indicated whether the user is correct or incorrect (Figure 34). Finally, the section concludes with a button labeled *FINISH* that directs the user to the conclusion of the virtual field trip.

Figure 34: Assessment questions for Enclaves section including answer choices and lightboxes. Question 1 correct answer: viscosity. Question 2 correct answer: True.

4.7 Conclusion

The conclusion page of the virtual field trip features text that thanks the user for their time and support for the website. The conclusion page also includes acknowledgements and further information regarding contact information and instruction for asking follow-up questions.

5. Discussion

5.1 How the Yosemite Virtual Field Trip Promotes Successful Learning

Many outstanding factors make taking students on traditional field trips difficult. Professors and teachers often do not have the time, money, or convenience to take their students on a field trip. As an alternative to traditional field trips, this virtual field trip website provides an accessible, engaging, and effecting learning experience regarding the magmatic history of Yosemite National Park.

This virtual field trip provides a service that is accessible for everyone at any time. The virtual field trip is free, ensuring that there are no financial limitations for users to access the content via the internet. The website also provides an equitable learning experience for people with various abilities. Subtitles are provided for every video included on the website so that viewers with hearing impairments may engage in the activities. Virtual hiking portions of the website provide users with physical limitations to experience Yosemite National Park's beautiful trails and landscapes from the comfort of their own home. Additionally, the virtual field trip is time efficient. The entire virtual field trip can be completed in under one hour for the majority of users. Traditional field trips typically require multiple days of commitment due to travel time. However, this virtual field trip allows for viewers with overarching time commitments, such as a full-time job or a family to care for, to complete a field trip and learn about magmatic features of Yosemite National Park without the stress of fitting it into their schedule.

This virtual field trip provides an engaging, interactive experience. The website is carefully formatted to be appealing to the eye and easily navigated. This is achieved by having the content organized into sections that can be accessed through a title menu (Figure 7) or by following the order of the content that will redirect users to the next section via navigation buttons. Various types of media are implemented into the website including videos, audio clips, text, photos, and cartoon images. The use of multi-media provides an engaging experience for users as it contrasts the typical text-heavy format of a textbook or the lecture-heavy format of a classroom. Additionally, interactive elements of the website prompt users to connect with the content. Buttons, lightboxes, hover photos, and slideshows successfully engage users by offering items that students may click or navigate through. Finally, the virtual field trip location of Yosemite National Park presents an engaging experience. Yosemite National Park is desirable to many people due to its beauty and scientific history and will be familiar to the majority of users. This acts as a marketing tool that entices viewers to begin the virtual field trip. These combined elements create a virtual field trip experience that is engaging.

Further steps were taken to affirm the effectiveness of the virtual field trip in communicating the content. The various forms of media implemented on the website provide content for visual, auditory, and kinesthetic learners. Videos, photos, and graphic images are provided for visual learners. Videos and audio recordings are provided for auditory learners. Lab activities and interactive elements (i.e. buttons, slideshows, etc.) are provided for kinesthetic learners. These various forms of media allow for a virtual field trip experience that effectively communicates content for all viewers.

This virtual field trip effectively educates the students on the magmatic story of Yosemite National Park. Instructional scaffolding is implemented into the structure of the website. The user begins learning about broader geologic concepts such as geologic time (i.e. relative and numeric dating), magma intrusive behaviors, the definition of a mineral, and rock classifications (i.e. felsic, intermediate, mafic). Later sections of the virtual field trip expand on these concepts to discuss more complex ideas regarding magmatic features. For example, the initial understanding of relative dating in the *Geologic Time & Yosemite's History* section allows for students to effectively understand the concept of Steno's Law of Cross-Cutting Relationships in the *Magmatic Features: Dikes* section. Additionally, the introduction of mineral composition in the *Mineralogy* section allows for students to effectively understand the interaction of magmas with felsic and mafic compositions in the

Magmatic Features: Enclaves section. The instructional scaffolding provided on the virtual field trip acts in contrast to a typical geoscience textbook. Introductory geology textbooks first teach about geologic time, then minerals, then the rock cycle without application to real-world examples or explanation as to the importance of learning such concepts. This virtual field trip website provides scaffolded teaching techniques similar to a textbook and applies these concepts to magmatic features in Yosemite National Park, giving students a format to apply these concepts to the real-world. Additionally, this virtual field trip includes leading questions, goals, and definitions on each section. These elements help students take geoscience terms and connect them to a bigger picture, giving them a purpose as to why they are studying this topic.

Finally, the virtual field trip is effective by presenting topics as they apply to real-world scenarios by discussing magmatic features and using analogue models. Furthermore, this virtual field trip provides a unique experience that connects for students to learn about magmatic features. Geoscience textbooks do not typically cover magmatic features such as dikes, enclaves, and stoped blocks. This virtual field trip provides a unique experience to students as it discusses these topics in detail as they occur in Yosemite National Park. Not only does this solidify geologic concepts by applying them to the real world, but also provides a place where students can expand their knowledge on topics that would not be covered in an introductory geology course. Additionally, this virtual field trip uses analogue models to apply concepts to real-world scenarios. For example, geologic time was illustrated on a football field (Figure 12), the process of stoping was reflected through ice cracking (Figure 26), and magma mixing was depicted through the oil and water activity

(Figure 31). This relation of geologic topics to the field and to real-life scenarios help to communicate the content effectively to students.

6. Conclusion

While the virtual field trip provides an accessible, engaging, and effective experience for users, there are many opportunities for further expansion and research. This design of a virtual field trip for the magmatic story of Yosemite could expand to different content areas (i.e. glaciers, hazards, climate change) or locations (i.e. Joshua Tree National Park, Yellowstone National Park). The format of the virtual field trip may also be adjusted to provide a more inclusive experience. For example, the website content could be translated to various languages so that users could experience the virtual field trip regardless of their English language proficiency. Additionally, the virtual field trip could be adapted to different formats. A three-dimensional tour, as seen in Dr. Hollister's (2016) Columns of the Giants virtual field trip, may allow for students to achieve a more interactive, realistic experience of visiting Yosemite National Park. Alternatively, the virtual field trip website could be adapted to a smartphone application, as presented in Dr. Natalie Bursztyn's (2017) Grand Canyon National Park virtual field trip. A smartphone application could provide a more accessible experience as it would not require a computer for use.

Research opportunities are available using the virtual field trip website. A study done in an introductory geoscience classroom could test the engagement and effectiveness of the virtual field trip. Expected results may include an increase in understanding of magmatic behaviors and an increased interest in the geoscience field.

As virtual field trips make their appearance in the field of geoscience education, their impact on the future of learning will be interesting to observe. Virtual field trips, such as this one, provide a fun, effective, and accessible tool for teachers and students to expand their knowledge of geology and potentially even grow a passion for science.

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