San Bernardino's Geologic History with 3D:

An Educational Exhibit for the San Bernardino County Museum

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Objective

To produce and provide an interactive exhibit with 3D scenes of significant geologic localities in San Bernardino for the San Bernardino County Museum. The exhibit provides a starting point for the museum to provide residents with a fun and interactive exhibit explaining the County's extensive geologic and paleontological history through the lens of 3D.

Abstract

San Bernardino is the largest county in the contiguous United States covering approximately 20,105 square miles. This means a lot of its residents and visitors are not able to make the trip to the county museum, even when it is open. In response to this, the San Bernardino County Museum (SBCM) has been exploring some digital education and exhibit options to continue the ever important public service that they provide. SBCM wants to begin this process within the Earth Sciences Division, providing a web based exhibit explaining the rich geologic and paleontological history of the county. SBCM wants to incorporate some key learning objectives such as the geologic time scale, depositional environments, and paleogeography. From these learning objectives, SBCM wants to encourage viewers to visit sites and the museum in person. Expectations for the final product include a low cost, comprehensive, and easy to use web-based exhibit that includes 3D elements. The 3D medium is incorporated to boost interactivity with the exhibit. The purpose of this project is to create build an exhibit for the San Bernardino County Museum to explain the geologic history of San Bernardino through 4 sites. Each site is represented with a 3D Scene. The models consist of a representation of specific outcrops that provide a large amount of fossils and historical context. The sites include the San Timoteo Formation, Rainbow Basin, Aztec Sandstone, and The Marble Mountains. Site models are generated using topographic Scene maps with ArcGIS Online, presented through an Esri StoryMap.

1.0 Introduction

1.1 Shareholder expectations and Scope

The San Bernardino County Museum (SBCM) is partnering with the Pennsylvania State University (PSU) to design and build an interactive virtual exhibit with 3D elements. This project is expected to fulfill the needs of the museum as well as the University's Master's Capstone. The museum has requested a virtual web-based exhibit that tells the story of San Bernardino's geologic and paleontologic history while explaining important geologic concepts such as the geologic time-scale and depositional environments. This is done through the lens of four important geologic sites from within the County, presented in chronological order (oldest to youngest sites). The exhibit is made for an audience of all ages without a scientific background and emphasizes the following learning objectives (Table 1). After viewing the exhibit, the viewer will be able to have an understanding of these elements, and consider visiting these sites, and the museum in person.

TABLE 1: EXHIBIT LEARNING OBJECTIVES

1	How can we tell geologic time with sedimentology, fossils, and the geologic time-scale?
2	Paleogeography – What did the County and the world look like at each time period?
3	Environmental reconstruction – What did the local ecology (paleo-environment) look like during each time period?
4	Present the locality as it is now.
5	Encourage visitors to visit each location and the museum

While the museum would like to touch on each of these learning objectives, they are also requesting incorporating a spatial 3D component. This is presented in the form of four 3D scenes or experiences of the selected sites: San Timoteo Formation, Rainbow Basin, Aztec Sandstone, and The Marble Mountains. Expectations of the product itself are outlined by the museum.

TABLE 2: MUSEUM EXPECTATIONS FOR THE FINAL PRODUCT

1	A comprehensive, low-cost, flexible, and easy-to-use virtual web-based exhibit to facilitate students' learning in geology by helping them better comprehend sedimentary structures and their 3D spatial arrangements.
2	Facilitating students' spatial visualization ability by developing interactive 3D scenes to visualize different geologic sites in San Bernardino and associated fossils.
3	Explain important geological concepts at an elementary level such as how we infer depositional environments and the geologic timescale.
4	Provide a workflow and necessary models used to create 3D spatial scenes.

The scope of the project entails these deliverables by or on December 2nd, 2021. The museum would like to have these deliverables be used for future projects that include an in-person exhibit with AR. The end product keeps this possibility in mind but it is not a part of the scope for this project. We delivered the product in the form of an Esri StoryMap with all associated scenes, models, and work-flows hosted within their organizations ArcGIS Online account.

1.2 Why Go Virtual?

The San Bernardino County Museum serves the largest County by area in the contiguous United States at around 20,105 square miles. To provide a more spatial comparison, it is a bit larger than the State of West Virginia and larger than the entire country of Switzerland. Most residents

who do not live in close proximity to the museum may not be inclined to drive upwards of 4 hours to visit, especially since the museum is not centrally located (figure 1). A virtual exhibit allows the museum to reach more people within and outside the County. As of 2021, 93% of US adults have access to the internet (Pew Research Center, 2021). This means that by going virtual, the museum

Figure 1: A map of California and San Bernardino County. SBCM is shown with a red point in the far left corner of the County in Redlands, CA.

can reach more people in and outside of the County.

Museums and many establishments across the world have been greatly affected by the COVID-19 pandemic and the museum is no different. Although the museum is now open at limited capacity, a lot of potential visitors are apprehensive to collect in public areas. A virtual exhibit allows those who choose to stay home to still have an enriching experience provided by the museum.

1.3 Why 3D?

3D and virtual experiences allow students or the general public to visit important locations otherwise inaccessible due to economic reasons, dangerous terrain and wildlife, or weather (Parong, J. & Mayer, R. E., 2018). However, incorporating 3D in our educational curriculum can also improve participation, critical thinking and social skills. There are a number of articles on the pedagogical impacts of 3D technologies. Many studies have found that students are able to absorb more information and are able to understand 3D concepts when they are presented in 3D (Abdinejad, M., Talaie, B., Qorbani, H.S. et al, 2021). We have established that 3D is an exciting way to learn and has captivated educators in the past. However, would 3D be beneficial in teaching geologic concepts? Geology and Earth History is in part taught through stratigraphy, a complex

three-dimensional construct. Sometimes, to infer what lays below geologists can observe outcrops or analyze the strike and dip of geologic structures. The museum has decided that the best way to explain Earth History and sedimentology would be through 3D experiences at various geologic strata. 3D has been proven to effectively teach complex geological concepts to beginners, more so than 2D maps (Mathiesen et al., 2012).

In addition to 3D being a beneficial tool for geology and education, museums highly benefit from incorporating interactive components in their exhibits. Musems serve as information communication sites by exhibiting their artifacts and by deploying appropriate information communication methods. It has been shown that museums increase interaction by including all forms of media (Latos, A., Komianos, V., & Oikonomou, K., 2018). While there are many reasons why the museum has decided to incorporate 3D in the interactive portion of the virtual exhibit, there are some recorded downsides to using interactive 3D as a learning tool. The main complaint is a large learning curve and technical issues with using the interface. Because of this, through product design we have to account for the user experience and make sure use of the exhibit is as seamless as possible to end users.

1.5 Study Area

The goal of this web-based field trip is to tell a comprehensive history of Earth and life on Earth with just a handful of sites found in San Bernardino County. The exhibit begins as a web-based 3D experience but will hopefully have many applications that can be used for an in-person AR experience later, outside the scope of this project. The exhibit shows a geologic map of San Bernardino and a geologic time scale, allowing the user to "move through time" in the county. Each virtual reconstruction displays a 3D scene reconstructed from modern geologic sites. Since San Bernardino County spans so much land area, it includes vastly different terrain and geology. It is in fact possible to stitch together a semi-comprehensive Earth history with just a couple localities in San Bernardino County (Figure 2). Because of this, the goal is to choose locations ranging in geologic age from the Cambrian (550,000,000 years ago) to the Pleistocene (2,500,000 to 11,000 years ago). The scope of this project encapsulates the curation of four locational 3D scenes that can later be embedded into this web-based exhibit in the form of a StoryMap.

Figure 2: San Bernardino County Study Area: four points indicating geologic localities and one point indicating the location of SBCM

The oldest site can be found in the Marble Mountains within the Mojave Desert near Cadiz, CA (Figure 3 A). This locality is known for the well-exposed Latham Shale, Zabriskie Quartzite, Chambless Formation, and Cadiz Formation. The Latham Shale produces and abundance of Olenellid trilobites, brachiopods, and hyoliths. More rarely, eocrinoid echinoderms, segmented worms, soft-bodied algae, and the appendages of the giant Cambrian predator Anomalocaris have been found (Durham 1978; Mount 1980; Briggs and Mount 1982). Trace fossils are quite common, in which we find 'traces' of animal activity. Above the Latham Shale lies the Zabriskie Quartzite, which has yielded some burrows. The Chambless Formation lies above both the Latham and Zabriskie and primarily consists of grey limestone. The Chambless Formation has produced specimens that are comparable to stromatolites and are referred to as oncolites along with some traces of hyoliths and trilobites (Mount, 1980). Above the Chambless Formation lies the shale and sandstone dominant Cadiz Formation. Here we can find trace fossils and a few lower Cambrian Olenellids (Mason, J. 1935). In this model we use a locality that shows all of these formations so that we can thoroughly explain the depositional environments and fossils.

The next stop on our geologic tour is the Aztec Sandstone, found near the California/Nevada border. It consists primarily of sandstone and mudstone (Figure 3 B). The Aztec Sandstone is dated back to around 200 million years ago, in the Early Jurassic (Porter, M.L., 1987). This site records dinosaurs in California, which is an unusual occurrence. Evidence of Grallator-type footprints have been found in the formation, along with Navahopus footprints and evidence of Pterosaurs and trace fossils (Hilton, 2003). The model for this location highlights a small are in the Mojave where we can see lenses of this formation.

The Barstow Syncline, commonly known as Rainbow Basin, is next on our list. In addition to this location being particularly eye catching for its variable color, it produced a large variety of sediments of Miocene (23,000,000-5,000,000 year old) age containing fossils (Figure 3 C). This site can be split into three distinctive formations: Jackhammer, Pickhandle, and Barstow (Wooburne, 1990). The Jackhammer Formation is characterized by sandstone, siltstone, and some conglomerates. The Pickhandle formation displays some volcanics with deposits of tuff, rhyolite, and andesite. On top of the Pickhandle and Jackhammer lies the Barstow Formation, which is famously known to contain some of the largest assemblages of Cenozoic fossils in North America. The Barstow Formation is similar in composition to the Jackhammer formation aside from the inclusion of shale and a distinct charcoal black color (Wooburne, 1990). The Barstow Formation produces many small Miocene mammals but also some large mammals such as camels, horses, and mastodons. The model shows the full syncline and rainbow layers; however, the Barstow Formation is not shown in the syncline itself.

The most geologically recent formation to be explored is the San Timoteo Formation found commonly in Redlands, CA in the San Timoteo Mountain Range (Figure 3 D). The San Timoteo Formation is classified as highly paleontologically sensitive, and includes fossils of terrestrial mammals from the Pleistocene (2.5-1.5 million years ago). The stratigraphy is quite variant with white, green, and red sandstone, siltstone and conglomerates. The formation is split up into various beds most famously researched by Frick in 1921. Many terrestrial mammals were recovered such as ground sloths, camels, horses, saber toothed tigers, and mammoths. This formations continues to be an active site of interest to paleontologists. The locality shows the large variation of sediments within this formation.

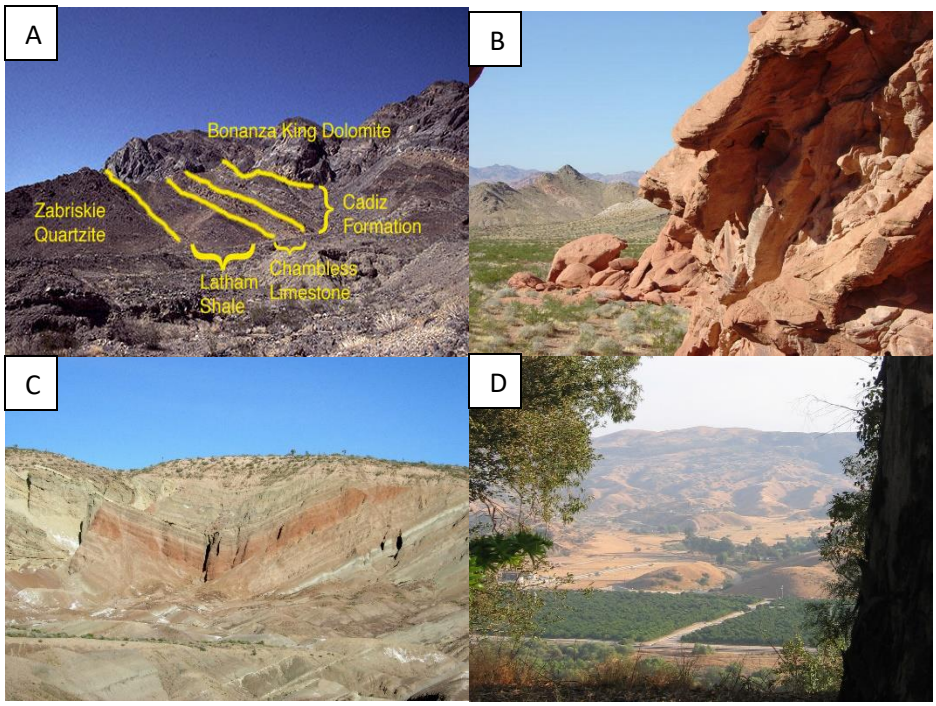

Figure 3: All four localities to be modeled. On the top left, Marble Mountains is pictured with some helpful labels indicating geologic formations. B shows an example of the Aztec Sandstone found in both San Bernardino County and Nevada. C represents Rainbow Basin and D shows San Timoteo Canyon in Redlands, CA.

2.0 Methodology

2.1 Making 3D Scenes

2.1.1 Geology Map Overlay

Some sites in the final product utilized a geology map overlay. This may consist of polygons displaying the boundaries between important geologic features and symbolizing them accordingly before overlaying them on a 3D scene.

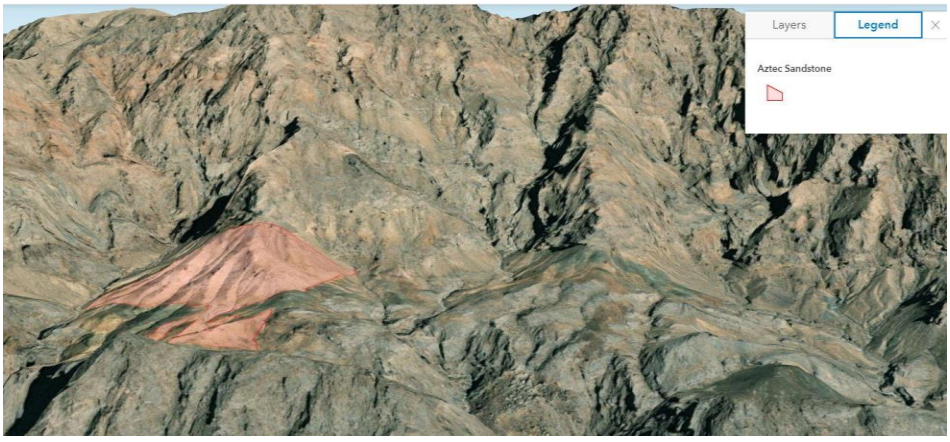

Figure 4: Aztec Sandstone is shown in the map by a red border and semi-transparent red fill.

Aztec Sandstone is less of a locality and more of a geologic unit that contains an abundance of fossils. It is present in Southern California but mostly in small lenses. For our 3D representation of Aztec Sandstone, I found it pertinent to outline this outcrop in the scene so as not to imply the entire mountain is made of up Aztec Sandstone (Figure 4).

2.1.4 Esri Imagery Basemap Overlay

The Imagery Basemap provided by Esri has an incredible amount of detail and was able to consistently display important geographic and stratigraphic information. Even open-source orthoimagery does not stack up to the amount of detail provided by Esri's Imagery Basemap. It is also convenient as it the imagery is hosted on Esri's servers, ready for use, and loaded quickly and reliably. The workflow is very simple: apply the imagery basemap on a 3D scene, anchor the locality/perspective and publish to ArcGIS Online. Esri Imagery is shown in Figure 4 and was used for the majority of our 3D scenes. The only locality in which this imagery did not create a detailed enough image was of Rainbow Basin (Figure 5). This is reasonable considering Rainbow Basin is one of our most detailed localities with complex geomorphology.

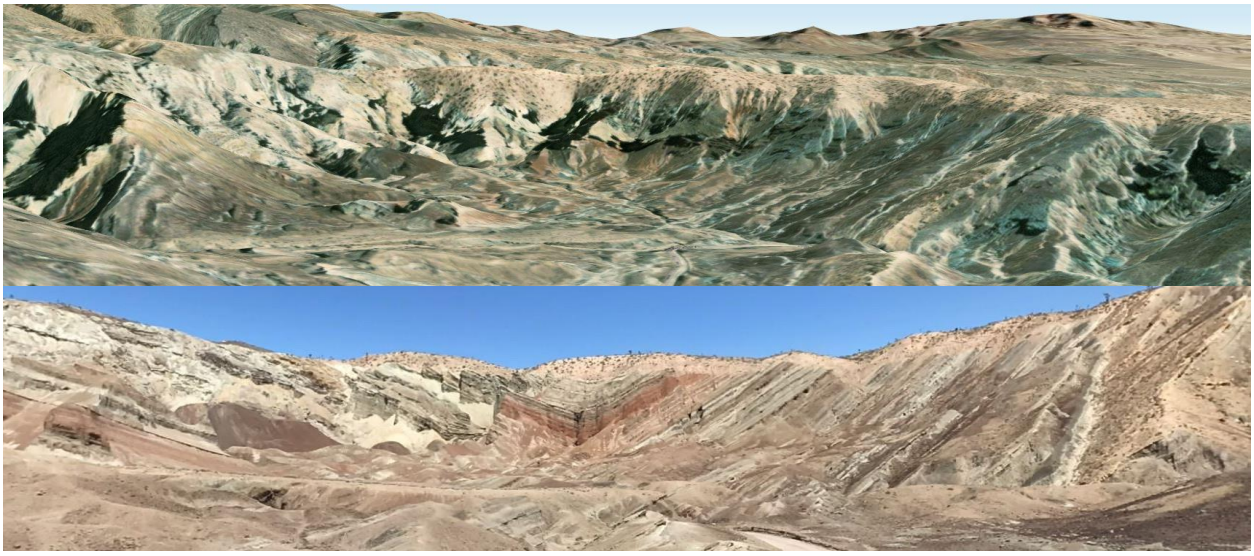

Figure 5: This figure depicts what the 3D scene looks like with the Esri Imagery (top) and what the locality actually looks like on Google (bottom). While some features are visible, a lot of important detail is missing.

2.1.5 Google Street View and 360 Degree Imagery

We used Google Maps 360 degree images to create the 3D model of Rainbow Basin by embedding the link from Google in our exhibit (Figure 5). There are some open source options to obtain 360 degree images, specifically from Google. Essentially, we found the locality in Google Maps and checked if there are any available 360 degree images. These images are crowd-sourced and appear as blue dots. After a visual inspection, the only thing to do is embed the link from Google into the exhibit.

2.2 Designing the Product

2.2.1 Building a Story

The exhibit was built using an Esri StoryMap and simply embed it into a museum webpage. The technical side of things and broader design is then handled by Esri and hosted on the museums organizational ArcGIS Online account for their viewing and future editing, if necessary.

In terms of building the story, we need to revisit the museum's needs and learning objectives in section 1.1 (tables 1 & 2). We are providing an exhibit on how geologists infer geologic history through stratigraphy, depositional environments, and fossils while teaching some geologic vocabulary and concepts along the way. We want the viewer to walk away with more knowledge on these subjects and potentially an urge to visit each locality, and the museum. The 3D models are an integral part of our final product and deliverable. The story is presented in the project in the following layout (Table 3) and each locality follows the same outline as shown in Table 4.

TABLE 3: STORYMAP OUTLINE

1	Geology can tell us a story - How do we read it?
2	Background information on the geologic time scale
3	Dive into each locality - starting with the oldest and moving to the youngest
4	Wrap it up and encourage users to visit each locality and the museum

TABLE 4: STORYMAP LOCALITY OUTLINE

1	Explain the paleogeography
2	Explain the geology, and how we can infer depositional environment from the geology
3	Introduce a couple important geologic concepts and vocabulary
4	Fossils found at each locality
5	Artistic environmental reconstruction
6	3D immersive locality to show the modern day location

2.2.2 User Experience

Through our research about how 3D can benefit museums and education, a big negative was user friendly technology. We strived to design a user-friendly product by including intuitive hints and pop-ups explaining how to use the product, and some of these features are already included by using the software as a service product of ArcGIS Online and StoryMaps. We will make indirect measures of learning objectives by soliciting feedback from stakeholders at the museum and users in the form of a survey created with the Survey 123 web application provided by Esri. Requests for ratings are shown in Table 5 and will tabulate the responses, and calculate the mean rating. This data will be used to improve the user experience.

TABLE 5: USER EXPERIENCE SURVEY QUESTIONS

1	Rate from 1-5 stars your overall experience using this exhibit
2	Rate from 1-5 stars the ease of use for 3D models
3	Rate from 1-5 stars your understanding of the geologic timescale before going through the exhibit
4	Rate from 1-5 stars your understanding of the geologic timescale after going through the exhibit
5	Rate from 1-5 stars your understanding of geologic history in San Bernardino before going through the exhibit

6	Rate from 1-5 stars your understanding of geologic history in San Bernardino after going through the exhibit
7	Rate from 1-5 stars your understanding of fossils in San Bernardino before going through the exhibit
8	Rate from 1-5 stars your understanding of fossils in San Bernardino after going through the exhibit
9	Rate from 1-5 stars the overall educational impact this exhibit had on you

3.0 Results

3.1 Deliverables

We provided the completed StoryMap with all requested elements to the museum. The StoryMap implemented each of the learning and project objectives and project objectives outlined in table 1 and 2 by teaching each subject in detail while encouraging visitors to get out an experience these sites in person or at the museum. The museum received three 3D scenes of Marble Mountains, Aztec Sandstone, and San Timoteo created with the Esri Imagery Basemap. The Aztec Sandstone model includes an overlay of the geologic border of the unit in the model. Although testing with both open source orthoimagery and photogrammetry, neither were included in the final product in the form of 3D scenes. There were, however, wonderful 360 degree images available of Rainbow Basin, which was implemented into the final product. For the museums future use, documented workflows were uploaded to their ArcGIS Online Organizational account.

3.2 Survey Results

We incorporated a user-survey to consider the user experience for the exhibit and provide an indirect measure of the previously stated learning objectives in table 1. We were able to collect 3 responses and are expecting many more. Figure 6 shows each question and the average rating of each user.

Museum Exhibit Survey Results : Sheet1

Survey Question	Number of Responses	Average Rating	Notes
Rate from 1-5 stars your overall experience uing this exhibit	3	5	
Rate from 1-5 stars the ease of use for 3D models	3	4.67	
Rate from 1-5 stars your understanding of the geologic timescale before going through the exhibit	3	3.34	
Rate from 1-5 stars your understanding of the geologic timescale after going through the exhibit	3	4.34	20% Increase
Your understanding of geologic history and biodiversity in San Bernardino before going through the exhibit	3	2.34	
Your understanding of geologic history and biodiversity in San Bernardino after going through the exhibit	3	4	40% Increase
Rate from 1-5 stars the overal educational impact this exhibit had on you	3	4.65	

Figure 6: User experience survey questions and average reported results.

5.0 Discussion

The museum exhibit was officially promoted on the museums social media accounts and published on their application as of December 13th, 2021. We were able to provide a comprehensive, low-cost, flexible, and easy-to-use virtual web-based exhibit. As stated, the goal of this project was to lay the foundation needed for the museum to use the materials provided to create more interactive and immersive exhibits. For this project, we completed an online web-based exhibit with 3D capabilities. We have also provided all of the files and scenes used to create the final product, along with documented workflows. Future goals for the museum include making an in-person virtual

reality or augmented reality exhibit. The design and final interface reached all of our design goals and fit the museum's objective to begin the process of incorporating 3D or more immersive experiences into their exhibits both virtually and in person.

6.0 Conclusion

In hopes of expanding their educational reach throughout their large County, The San Bernardino County Museum has partnered with the Pennsylvania State University in order to create and provide a virtual exhibit in the form of a StoryMap. This StoryMap set out to leave the user with a base knowledge of geologic history in the County. This includes knowledge of the geologic time scale, paleogeography, depositional environments, and fossils. The objective is for a visitor of the exhibit to walk away feeling confident in their knowledge of important geologic sites in San Bernardino County. As an added goal of the museum, we would like viewers to consider visiting the museum in person or even visit these sites as many of them have public hiking areas. The museum asked that this was done in a comprehensive and low-cost virtual exhibit. They had also requested a 3D element to the exhibit because of the added benefits of including an interactive 3D element to museum exhibits, and natural science education. Lastly, it was of high importance to make sure the end product was user friendly and adaptable for future projects.

The final product was provided in the form of a StoryMap presenting four sites in chronologic order based on their geologic age. Each site was presented with a visual representation of paleogeography, depositional environments, and fossils. Each site also included an interactive 3D scene of a modern day location. The museum received the StoryMap as a hosted item in their ArcGIS Online Organization, along with three 3D scenes of Aztec Sandstone, Marble Mountains, and San Timoteo. Rainbow basin was presented with a 360 degree crowd sourced Google image embedded into the StoryMap. They have also received a documented workflow for future applications.

As a virtual museum exhibit, there is no direct way of assessing learning outcomes. However, we were able to measure indirectly with a self-reported survey. From the self-reported survey, we were able to note that the overall experience using the exhibit was positive and learning objectives were met. Again, these results are self-reported and there is really no concrete way to understand what users will walk away from this exhibit with. The main goal is that they have a positive educational experience and consider seeing more of the County in person, including The San Bernardino County Museum.

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