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Three Dimensional Cartography for a Theater Production

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A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

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Abstract

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by
Chad Lopez

This report documents the planning, design, and implementation of the Three Dimensional Cartography for a Theater Production project. This project's client was Professor Chris Beach, a professor of Theater Arts at the University of Redlands. Professor Beach was interested in implementing 3D cartographic geovisualizations into a theater production he was co-writing. These geovisualizations were meant to be presented alongside actors on stage to a live audience. The datasets visualized include antique USGS topographic maps, National Park Service maps, orthographic photos and prehistoric petroglyphic cartographic representations. The process of implementing this project involved gathering raw data from internet sources, formatting them so they could be utilized on a 3D platform, and exporting animation tracks created from the data as videos. This project used ArcGIS software to create dynamic 3D cartographic representations that were visually appealing and engaging to an audience.

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Chapter 1 – Introduction

This report reviews the planning and implementation of 3D Cartography for a Theater Production presented by Professor Chris Beach of the University of Redlands, Department of Theater Arts. Section 1.1 introduces the client. Section 1.2 describes the client's problem and involvement. Section 1.3 describes the objectives, scope, methods and proposed product. Section 1.4 describes this report's intended audience. Section 1.5 describes the contents of the rest of this report.

1.1 Client

The client for this project was Professor Chris Beach, a Professor of Theater Arts at the University of Redlands. He received a BFA from Virginia Commonwealth University in 1977 and an MFA in Directing from the University of California at Los Angeles in 1992. He has directed over 60 productions both professional and academic. His primary areas of interest included acting, directing, voice and movement. Beach also provides training on public speaking to GIS professionals, specifically the Esri employees who present in the plenary sessions of the annual Esri User Conferences. He and his collaborator Kevin Crust were inspired to create a play featuring geographic information science. They interviewed several of their acquaintances with geospatial data experience on the subject of GIS in order to begin work on a stage production involving GIS, titled *Petroglyphs.*

1.2 Problem Statement

Professor Beach wished to create a stage production utilizing geovisualizations as set pieces and props. Specifically Beach wished to add visualizations of the ancient Puebloan landscape to coincide with the plot of his stage production. The characters in the production travel through ancient Puebloan land. These landscapes needed to be visualized for the production. Professor Beach wanted this production to introduce GIS to a wider audience. This means that any visualizations created needed to be visually appealing and worthy of a major theater production. Professor Beach wanted the visualizations to be created using authentic GIS methods, since one of the play's characters is a GIS expert. Maps needed to be created so that he could use them during the performance. Another character was a traveling photographer; visualizations of a journey she took during the plot needed to be created. Traditional 2D maps along with 3D views and visualizations were what were required for this stage production. This project involved stylistic data visualization.

1.3 Proposed Solution

Professor Beach's project required the implementation of three main requirements: 1) 3D visualization of the locations featured in the play, 2) these visualizations must be aesthetically pleasing and interesting to attract and impress a wide audience, and 3) support documents that provide a streamlined and easy-to-follow workflow for the creation of these visualizations by other GIS users at the University of Redlands.

1.3.1 Goals and Objectives

The first goal of this project was to provide visualizations that can be featured in the theater production. The plot of the play involved a geographic information scientist following his departed wife's prior travel around the American Southwest and national monuments that feature ancient Puebloan artifacts. The visualizations needed to be of areas that were relevant to the plot of this play. Professor Beach provided a book called *Where the Rain Children Sleep* by Michael Engelhard (2004), which gave insights on the geographic locations of the geovisualizations that were to be created by referencing locations and trails that were noteworthy to the ancient Puebloans.

Another goal was to make these visualizations engaging and aesthetically pleasing to a wide audience. These visualizations were provided as entertainment and were meant to be used as props or stage pieces that could be referenced to and interacted with by the characters.

The final goal of the project was to provide help documents so the process of creating these types for visualizations could be streamlined for users wanting to create a similar production in the future.

1.3.2 Scope

This project encompassed the visualization of four different sites in the American Four Corners region: Canyon De Chelly National Monument, Newspaper Rock National Monument, Sunset Crater National Monument, and Shavano Valley near Uncompahgre National Forest. Several raster datasets needed to be collected for each site to construct and display each 3D visualization. Many of these raster datasets needed to be formatted correctly so that they could be displayed in ArcGlobe. Unique 3D symbolization of vector data for some of the sites was also required. Another essential part of the project was the completion of the unique Shavano Valley Petroglyph sub-project, which involved rubber sheeting an image of a petroglyph to a geographic surface for the purpose of geovisualization.

In addition to creating the geovisualizations, help documents needed to be written to allow for fast and easy production of similar geovisualizations in the future. These help documents are intended to be read and implemented by undergraduate GIS students at the University of Redlands, and technical staff at the Center for Spatial Studies at the University of Redlands.

These visualizations were required to be completed before rehearsals of the play begin in 2016. This project was intended to occupy about 500 hours of work over a one year period.

1.3.3 Methods

It was important to choose the correct software to create the geovisualizations. The visualizations needed to engage the audience by being visually appealing. The client also decided that it was important for the visualizations to be dynamic. This meant that video would be the most ideal medium to portray these visualizations, so raster datasets were a way to display varying settings. These raster datasets needed to be formatted correctly before they could be displayed in 3D. This meant they needed to be converted to an image format and be georeferenced so they could be used and displayed in ArcMap alongside other datasets. After the raster datasets were formatted, the datasets needed to be displayed in high resolution with all quality intact. ArcGlobe served as the ideal application for this because it offered cross-platform compatibility with ArcMap and it offers display-centered functionality. This application was used to display and record videos of raster datasets draped on top of digital elevation models (DEMs).

1.4 Audience

This report is intended for an audience with a GIS technical background including cartographers interested in displaying their work to a wider audience in an unconventional manner. It is assumed that the reader knows some basic GIS concepts.

1.5 Overview of the Rest of this Report

The rest of this report provides a detailed overview of the project. Chapter 2 provides a literature review of studies relating to 3D representation and data presentation. Chapter 3 explains the functional and nonfunctional requirements of the project. Chapter 4 provides information about the data used in this project and where they came from. It also provides an overview of the data model and the logical database design. Chapter 5 gives a detailed description of the implementation of this project. Chapter 6 reviews the final results and Chapter 7 provides a project conclusion and suggests possible future work.

Chapter 2 – Background and Literature Review

This project encompassed an eclectic variety of disciplines including archaeology, education, fine arts, 3D visualization, and GIS. This chapter reviews previous works and studies conducted within the project's respective fields. Such background research is important for understanding all of the pieces that make up this project. Section 2.1 describes the benefits gained from sharing GIS with a wider audience. Section 2.2 outlines the fundamentals of 3D visualization. Section 2.3 references previous work concerning 3D GIS representations of archaeological sites. Section 2.4 provides background information on the Shavano Valley petroglyph that was georeferenced in this project. Section 2.5 describes the projection mapping technique (a video projection method) and how it is a tool for the graphic representation of data.

2.1 Sharing GIS

A nonfunctional requirement of this project was to share GIS with a wider audience by exposing them to GIS through a stage production. Demirci (2008) talked about sharing technology with a wider audience through the classroom, explaining that GIS can be a useful tool in a variety of subjects, such as earth science, chemistry, biology, mathematics, environmental science, social science, and geography. Demirci stated that learning GIS technology allows students to become more engaged in other technology lessons in the classroom. This engagement triggers higher-level critical thinking. Using GIS technology as a tool in a classroom can promote students' sense of inquiry and spark a student's interest in pursuing an education in science or engineering. However, in order for this cognitive development to take place it is important for teachers to be enthusiastic about the technology they are teaching. This requires that teachers first become familiar with the technology.

Lendenberger et al. (2006) explained that the use of GIS can make earth sciences exciting and cultivate a sense of inquiry through student-lead earth science projects. Exposure to GIS encourages scientific method-based thinking and the formation of hypotheses in secondary school students. It also exposes students to the concept of sharing data with fellow professionals across a global network. The author opined that these are important concepts for children to learn so that they are able to understand the environmental factors of the world in which they live.

White and Simm's (1993) research revealed that GIS serves as a catalyst for creative thought through allowing students to have firsthand experience with scientific tools. GIS technology teaches students about data collection and project management; both skills are integral to today's employment market.

2.2 3D Visualization

Three Dimensional images are more intuitive to the average audience than 2D ones. While 2D images work for the purpose of abstraction, 3D images add the extra element of immersion. Humans live in a 3D world; creating images in 2D removes some of the abstraction. This concept is evidenced in Figure 2-1 and Figure 2-2.

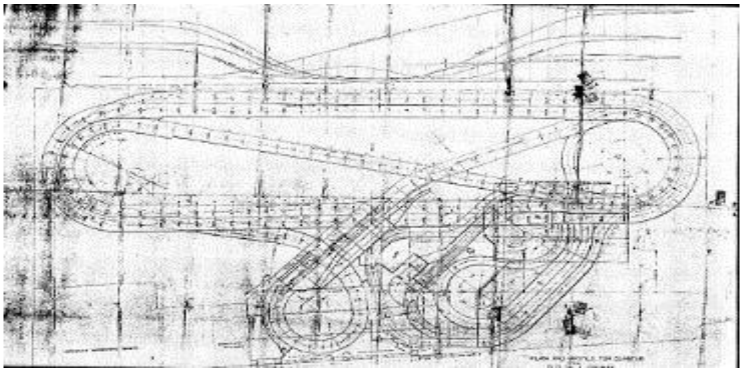


Figure 2-1: 2D Roller coaster blueprint (Miller, 1918)

Figure 2-2: Point of view roller coaster image (Galperina, 2014)

Noy (2005) explained that the purpose of geovisualization is to allow for easier comprehension of complex and abstract depictions of data. 3D visualization and most other computer-aided visualizations create illustrations that focus on data or concepts that are meant to be communicated without highlighting all of the other noise that is not essential to understanding the main concept. Computer-aided visualization allows users to turn off non-essential data layers and focus on those necessary for comprehension. Computer-aided visualization increases a user's ability to query the information or data that they require, and allows users to input synthetic data and compare them to real world datasets. Bodum and Jernes (2004) opined that 3D data are especially useful for allowing users to navigate and familiarize themselves with a 3D data landscape and this greatly aids in comprehension. Wood et al. (2005) concluded that cartographers use 3D representations because they are easier and simpler for users to understand. It requires less effort to put 3D representations in context. 3D also strengthens dynamism, visualization and interaction and gives users the opportunity to explore representations almost as they would in a 3D virtual environment. This type of exploration has been popularized by the video gaming industry. 3D can aid in the visualization and cognition of complex temporal data.

Haeberling (2002) defined 3D maps as computer-generated perspective views of geographic or spatial data. While the maps are technically 2D because they appear on a 2 dimensional screen, human eyes perceive them in 3D. The process of designing a 3D map first involves converting geographic datasets to a format in which they can be represented in 3D. After the data are represented in 3D, they are symbolized to make comprehension easier. Haeberling wrote that the appearance of a map depends on numerous graphic aspects (groups of parameters that exert different effects on the arrangement or appearance of the objects within the map). He defined two classes of graphic aspects: graphic aspects of modeling, and graphic aspects of symbolisation. Examples of graphic aspects of modeling include: data extent structure (a dataset depicts a rectangular section of land vs. a continuous one), data format (raster dataset, vector, external 3D objects), and orienting objects that assist the user with extracting geographic information (such as coordinate lines). Graphic aspects of symbolization include: object positioning, shape, size, color, brightness, textures, patterns, and orientation. As with traditional cartography, all of these aspects significantly affect how a map viewer will perceive information or receive a message. Haeberling (2005) explained that cartographic conventions for 3D maps do not exist yet. He proposed a number of cartographic conventions for 3D maps: abstraction, dimension degree, camera aspect, lighting aspect, and atmospheric effects. Another important factor in visualizing 3D data is vertical exaggeration, which can be used to emphasize subtle changes in a surface. This can be useful in creating visualizations of terrain where the horizontal extent of the surface is significantly greater than the amount of vertical change in the surface. A fractional vertical exaggeration (<1.0) can be used to flatten surfaces or features that have extreme vertical variation. Wood et al. (2005) proposed a model for the process of 3D visualization consisting of several steps. The first step is data management or getting access to the raw data. The second is data assembly or processing the data for the purposes of visualization. The third is visual mapping, converting and transforming assembled data by means of 3D graphics, and producing a 3D representation of the data. The fourth is rendering or synthesizing 3D views to produce a 2D image. The fifth is display or using output media to display a 2D image. The last step is schemata or the user's ocular and cognitive processing of an image.

A study conducted by Schmidt, Delazari, and Mendonça (2012) on perspective view showed that users prefer a coordinate grid for reference when making spatial decisions when exploring a 3D map. Without a reference grid it is easy for users to become disoriented when looking at the map. Schmidt, Delazari, and Mendonça also concluded that symbols constructed from 3D shapes are easy to read and therefore aid in the understanding of the map. They concluded that a brighter sky color (blue) also aids in correctly understanding a perspective map that includes the horizon.

Domajinko, Fras and Petrovič (2008) referenced three types of 3D cartographic visualizations draped image, photo-realistic, and abstract cartographic model.

A draped map which is simply a digital terrain model (DTM) with a 2D raster image draped over it. This raster image could be photo realistic or it could be abstract such as in a standard topographic map (Figure 2-3).

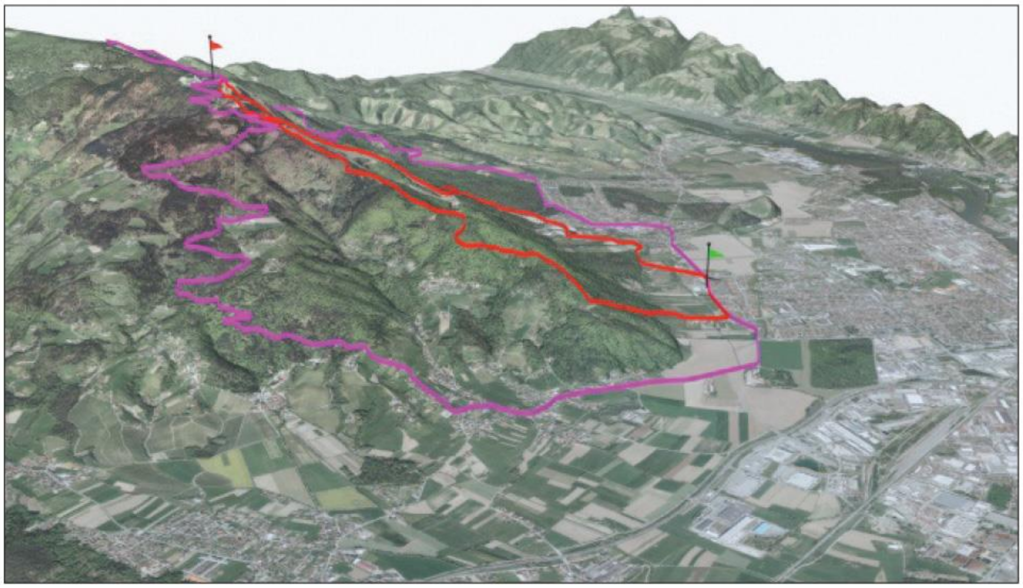


Figure 2-3: Draped map; orthophoto overlay (Domajinko et al., 2008, p.4)

A photo-realistic cartographic model which has enough graphical detail to prevent an unrealistic visual result from the observer's point of view (Figure 2-4). These maps contain 3D graphical elements and may allow for interaction. They are designed to replicate the view of real world objects.

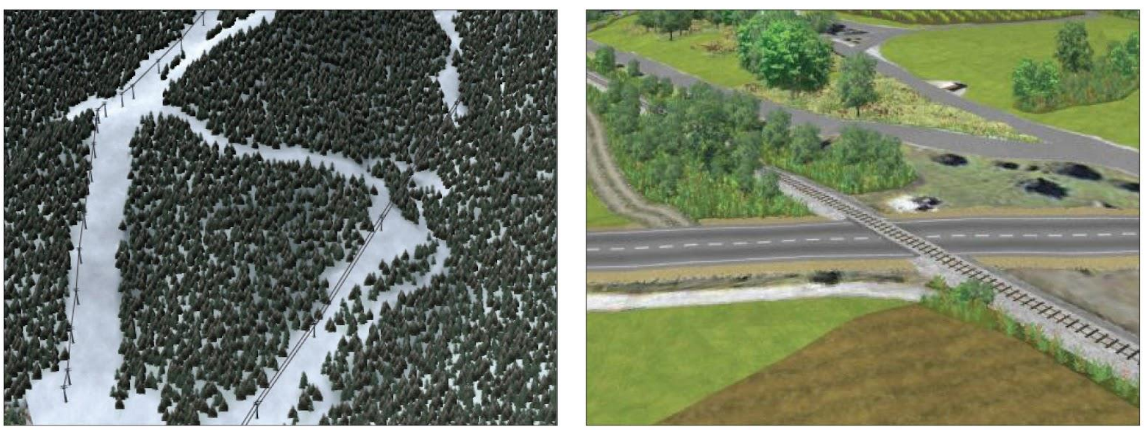


Figure 2-4: Designing of photo-realistic 3D map content; ski slope (left) and road infrastructure (right) (Domajinko et al., 2008, p.5)

An abstract cartographic 3D model (Figure 2-5). These visualizations utilize generalization and abstraction for quick and clear cartographic communication. These models most closely resemble traditional maps.

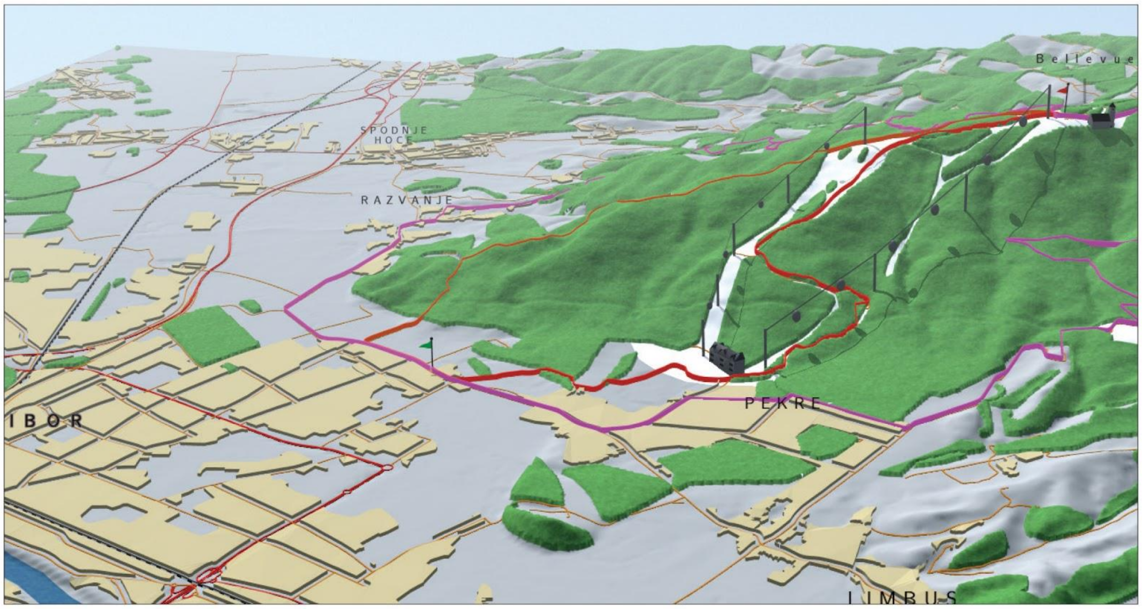


Figure 2-5: Abstract 3D map. (Domajinko et al., 2008, p.6)

Domajinko and others explained that photo-realistic models are great for the general public because they look realistic, natural, and are easy to understand. Abstract models are best for experienced map users for the purposes of information generalization and analysis. Petrovič and Mašera (2004) conducted a study on map user preferences and found that users prefer draped 3D topographic maps rather than traditional 2D versions, because 3D versions allow for height and direction to be represented. They also found that users prefer topographic maps over other abstract map representations because they are familiar.

2.3 3D GIS Visualization in Archeology

3D visualizations have great potential for applications in archaeology. The Bologna City Council provided convincing evidence of this when they developed the Electronic Museum of the Certosa Cemetery (Diamanti et al. 2004). This application was created by draping aerial photography over a digital elevation model and adding 3D structures to enhance visualization. It provided a simple interface with features including navigating the cemetery and querying for information about specific cemetery subjects. Space and time were used to organize the application into different periods. Matison (2012) described 3D visualization in archaeology as a simple way to illustrate archeology for the masses. He explained 3D visualization of archaeological sites allows for the overlay of 3D data on top of real world pictures. This creates augmented reality.

Barnash (2011) developed a method to determine the visual significance of peaks to the Hopi Culture. She used the Douglas-Peuker algorithm to measure the prominence of peaks from a ground perspective. Significant peaks influence the viewer's memory of a landscape and can help archeologists gain insight on social importance of certain features within a landscape.

2.4 3D Visual Fly-Throughs

Other software have been used to create 3D visual fly-throughs such as Google Earth and Tinman 3D. These software produce realistic imagery of landscapes. They utilize elevation data along with orthographic imagery. YouTube uploader Paul van Dinther produced a fly-through video of the Grand Canyon with a white line that indicates the track of the camera. Videos produced using these applications allow users to explore landscapes as if they were flying through them using a helicopter. They allow for almost an almost seamless combination of elevation and imagery data. Examples of Google Earth 3D fly-throughs and Tinman 3D fly-throughs can be seen in Figure 2-6.

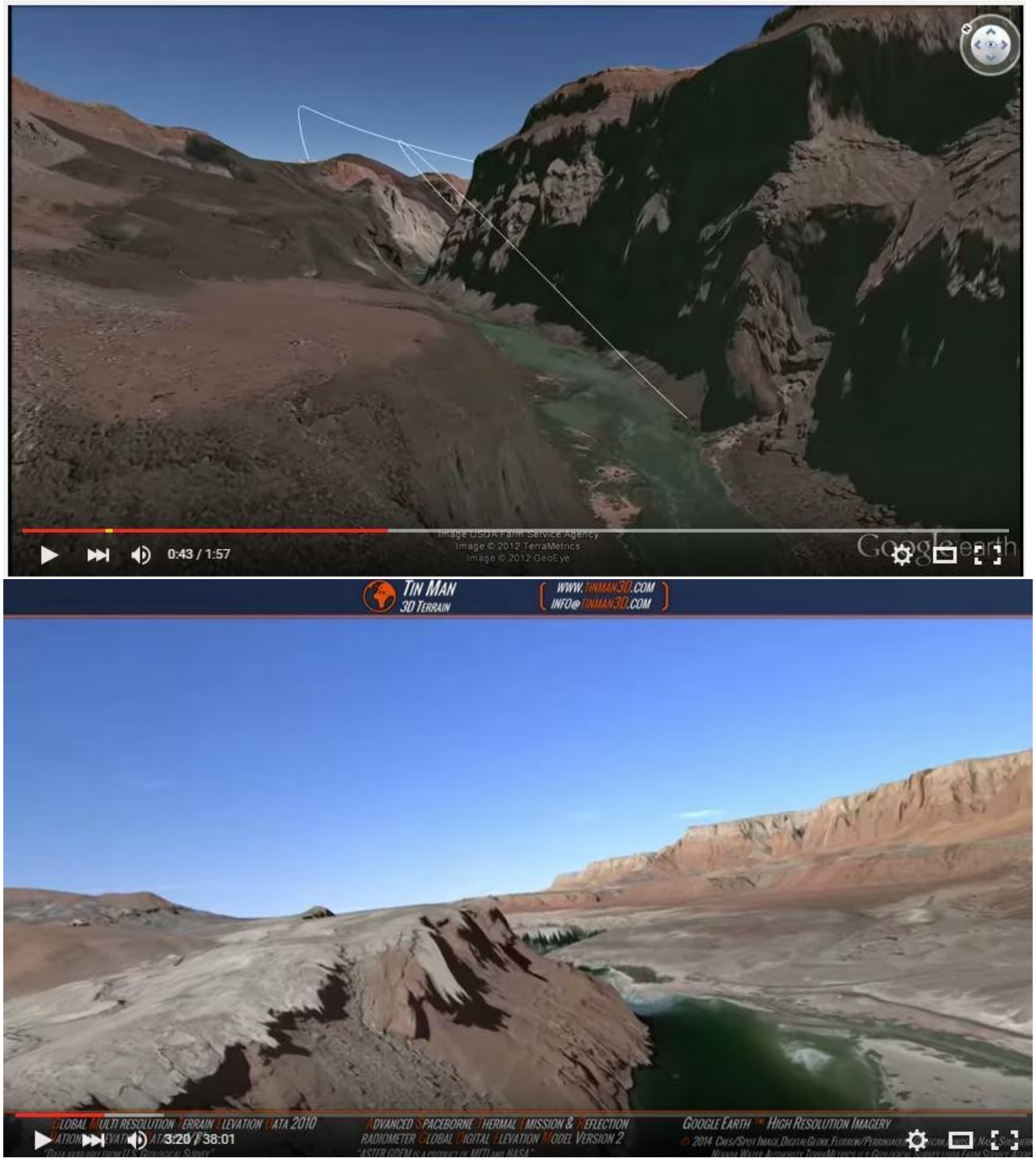


Figure 2-6: Top: Google Earth fly-through (Paul Van Dinther, 2012), Bottom: Tinman fly-through (Matthias Englert, 2009)

2.5 Shavano Valley Petroglyph

This project also involved georeferencing a petroglyph (rock engraving made by prehistoric humans) that was believed by Patterson (2013) to be a cartographic depiction of the Shavano Valley region in southwest Colorado. The petroglyph was believed to have been created by the Ute people during their occupation of the region between A.D. 1400 and 1900. The petroglyph is described as an abstract linear feature that displays terrain data. It is made up of several wavy lines, straight lines and circles. It is believed to be a hunting map and the circles represent areas where animals gather during the winter.

Initial control points used to georeference the petroglyph were selected from the image that anthropologist Carol Patterson provided in her article (Patterson, 2013). In this image the petroglyph is overlaid on top of an USGS topographic map (Figure 2-7).

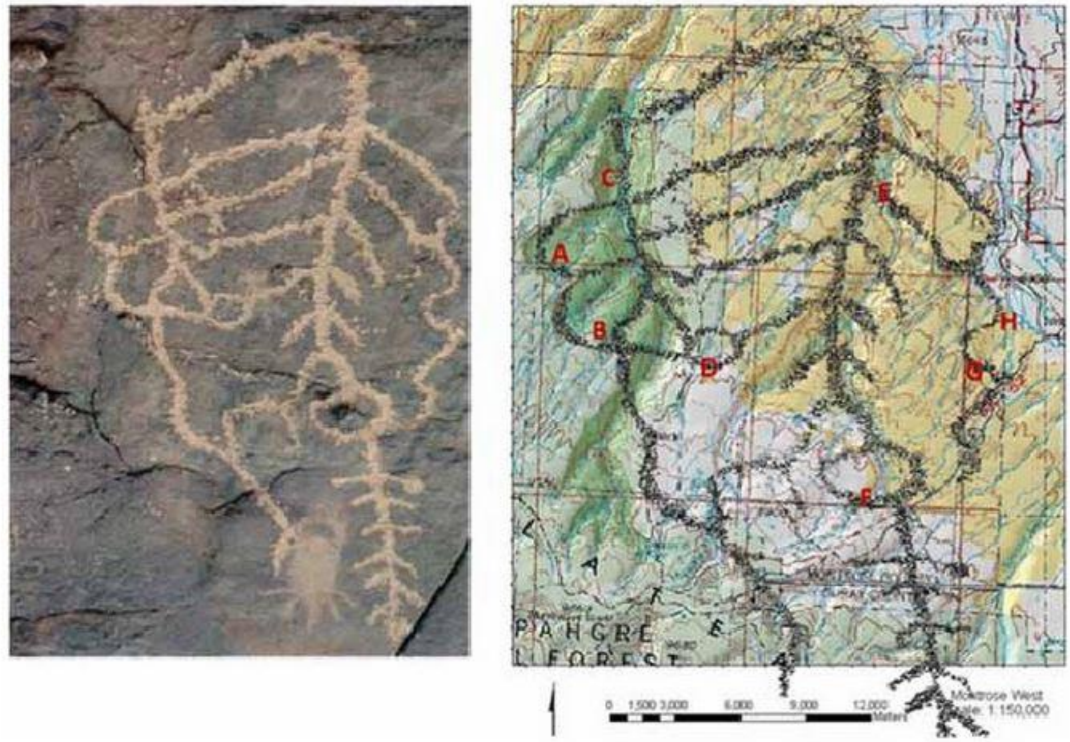


Figure 2-7: Overlay of the Shavano Valley petroglyph (Patterson, 2013, p.6)

Whelan (2003) completed a similar project in which she georeferenced historic Native American Ioway maps that depicted hydrography and villages. These maps were used in 1837 to support a historical claim to land that the U.S. Government was purchasing via treaties. These maps were georeferenced in order to match real word features to the Ioway Cartographic depictions. The georeferenced maps provide visual confirmation that real world features were depicted despite the lack of accuracy.

2.6 Projection Mapping

The client expressed his desire to showcase the cartographic representations using a technique called projection mapping. Lee et al. (2015) described projection mapping as a form of augmented reality. They portrayed projection mapping as a technique that can reinforce visual data by ‘throwing’ them on a real world 3D surface. This technique is used when traditional graphical or lighting techniques are unable to produce the desired visual effect. It can display high definition images that can change shape and flow with a real world 3D surface over time, displaying visualizations dynamically. Lee and others said that projection mapping is “a technique which causes an optical illusion by analyzing three-dimensional objects, projecting images, and then precisely aligning them” (Lee et al., 2015, p.5). More sophisticated systems are able to respond to an actor’s movement and can project on flexible shapes such as an actor’s costume. Ekim (2011) explained that projection mapping is a tool because it composes and edits programs to create projected images, but is also a medium because it presents the created images to audiences in a striking manner. Yoo and Kim (2014) explained that projection mapping produces an illusion of movement on previously static images or surfaces. Projection mapping is a powerful graphical tool for displaying a style of imagery that other mediums are unable to display.

2.7 Summary

GIS is an increasingly important part of our world. This means that it is crucial to share GIS displays with wider audiences so the general public is more equipped to comprehend spatial concepts. Advances in 3D visualization contribute to the accessibility of geospatial knowledge. 3D visualizations make comprehending spatial data easier and are important for the development of cartography as a discipline. This medium is also shown to have a profound impact in the archaeology field. 3D reconstructions allow for easier comprehension of archaeological spatial and non-spatial data. Projection mapping could serve as a highly influential tool for the presentation of 3D maps and 2D maps alike. The striking scenes projection mapping can produce can serve to draw more people into being enthusiastic about geospatial data.

Chapter 3 – Systems Analysis and Design

This chapter provides a description of the process used to implement the 3D Cartography for a Theater Production project. Section 3.1 reviews the problem this project attempted to solve. Section 3.2 reviews the functional and nonfunctional requirements used. Section 3.3 describes and illustrates how the different components of the system design fit together. Section 3.4 outlines the project plan that was designed to complete this project.

3.1 Problem Statement

The project's objective was to create aesthetically pleasing 3D visualizations for a 2016 stage production directed by the client Chris Beach. These visualizations were required to be of settings that were included in the play's plot. This project was strategically important to Professor Beach because the visualizations produced were a major part of the production and served to make the theater production distinct from other theater productions. This project was also significant because it displayed GIS concepts and technology to a whole new audience.

The project's critical success factors included making the maps aesthetically pleasing and accessible to a wide non-GIS audience so that anyone can enjoy them. Implementing the visualizations into the production was also a critical success factor. The maps would not be useful if they did not reach the intended audience.

3.2 Requirements Analysis

The main requirements of the 3D Cartography for a Theater Production project are listed in Table 1.

Table 1. System Requirements

System Requirement	**Functional/ Nonfunctional**
Use Esri ArcGIS 10.2.2 for visualization of 3D landscapes.	Functional
Visualizations must provide views of areas that are relevant to the play's plot.	Functional
Create videos of fly-by tours and bookmark tracks from the provided software for display.	Functional
Provide appropriate instruction and support documents so that undergraduate students or the professionals from University of Redlands' Center for Spatial Studies can easily recreate the project in the future.	Functional
Provide appropriate instruction and support documents so that the client and stage crew members are able to utilize the visualizations produced.	Functional
Visualizations must be accessible and aesthetically pleasing to a wide audience, not just an audience that is educated on GIS.	Functional
Visualizations are provided to the client before rehearsals begin.	Functional
Visualizations must be compatible with projection mapping software and hardware.	Nonfunctional

The Esri ArcGIS platform was a powerful tool to produce the visualizations of the locations depicted in the project. The visualizations needed to utilize raster images of the various sites using varying abstractions, such as USGS topographic maps, National Park Service maps, and photographs of ancient petroglyphs. These raster images needed to be displayed at the highest resolution possible. The images also needed to be fully rendered throughout the videos that were created. The raster images were to be displayed at full resolution in ArcGlobe.

The visualizations created needed to coincide with the play's plot. If visualizations do not coincide with the play's plot this would mean the failure of a functional requirement because the client would not be able to use the maps for their intended purpose. The maps would not aid in illustrating the client's story. ArcGlobe provides ways of auto-navigating 3D landscapes. In order for a video to be recorded a navigation track needed to be put in place. Fly-by tours and bookmarks served as the navigation tracks for the videos to be recorded. The videos are displayed in the theater production and accompany the actors on stage.

It is important for the stage crew to be able to utilize the material created for this project. For this reason information was provided on how to handle the spatial products provided. It was also important to provide instructional documents so that future project managers were able to recreate the project. A professor on campus or an undergraduate student may need 3D GIS visualizations for a new project, or Professor Beach may decide that he needs additional visualizations in his stage production. If this is the case, the University of Redlands Center for Spatial Studies is equipped with the instructional material needed to replicate this project.

The products were required to be aesthetically pleasing and accessible to a wide audience. A secondary objective of this project was to share GIS with an audience unfamiliar with GIS. The aesthetics contributed to the completion of this goal. The visualizations had to be provided to the client prior to the first rehearsal so that he could implement the visualizations into his production. This allowed the client to block his play and rehearse it with the visualizations in place. A nonfunctional requirement was that the visualizations are to be compatible with projection mapping software and hardware. This is because the client expressed his desire to use projection mapping as a means to display the products. This is a nonfunctional requirement because the client was still able to display the visualizations with traditional projectors. It was not possible to test this requirement because the projection mapping software or hardware were not accessible during project implentation.

3.3 System Design

The 3D Cartography of a Theater Production project system consisted of components that supported the creation, storage, implementation, and display of the 3D visualizations that were functional requirements of the project. The system consisted of 5 components: a data storage component, a data "cleaning" and geoprocessing component, a component that facilitated 3D cartography and navigation, a component that was able to convert the

3D visualizations into a video format, and a visualization component. Figure 3-1 displays the system design diagram

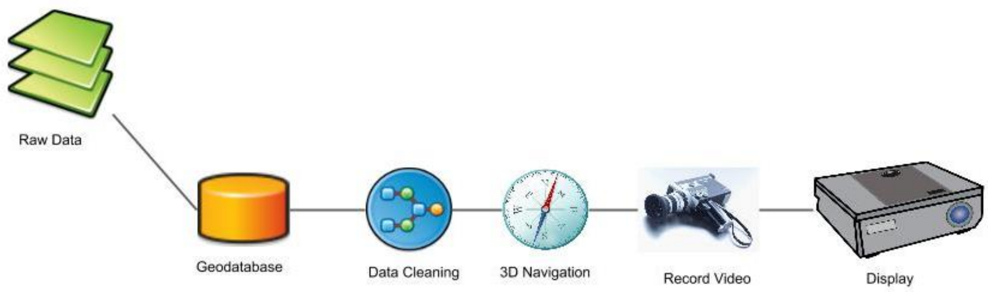


Figure 3-1: System Design Diagram

The database component stored all geographic data that were used in the visualizations. It stored all the data that were cleaned or resymbolized from their initial sources. Users were able to connect to the database from a desktop computer. Video files were stored separately so that they could be delivered to the client who did not have the software necessary to utilize geospatial data.

The data cleaning component was able to georeference unreferenced spatial data such as USGS topographic maps. This component also allowed for geoprocessing functions to clip out excess data that were not needed for the purposes of this project. This component allowed for manipulation of the data. ArcMap 10.2.2 serves this function well.

There was a component that allowed for display and navigation. The ability to navigate and display 3D dataset representations allowed for quality assurance before the creation of a video. Navigation methods included fly-bys and navigation through 3D bookmarks. ArcGlobe served this purpose well.

There was a component that changed the 3D tracks into videos. This involved exporting a video in the audio video interleaved (AVI) file format.

The final component presented displays of the visualizations. This component consisted of a desktop computer screen at the editing and production level. On a performance level the display is on stage through a traditional projector or using a projection mapping technique.

The database component was capable of running independently. It was capable of being moved and being used on other machines. It was also compatible with geoprocessing tools. It was viable for storing all relevant project data in one place. Files containing videos were also capable of being moved to, stored and used on other machines. The navigation component first depended on the cleaning component. Data first needed to be clipped to the proper extent and georeferenced in ArcMap before navigation could take place. Creating a video was only possible once a navigation track had been created. After a navigation track had been created a video could be recorded based on the track. The final presentation component could work independently of the others. The video products of the other components could then be displayed through a projector or a desktop monitor.

3.4 Project Plan

Table 2 outlines the process utilized to bring this project to fruition. Phase 1 is the initial project design. Phase 2 outlines the development of the project. It includes the steps used to create the 3D visualizations. Phase 3 outlines the deployment of the project − delivering the products to the client.

Table 2. Project Plan

Phase	**Task**	**Description**
1. Design		
1.1	Identify potential areas for cartographic representation.	Areas of representation were identified based on locations the client provided from his script.
1.2	Acquire appropriate data based on the study area.	Appropriate data were acquired from the USGS website and also from a previous thesis project completed by Barnash in 2011.
1.3	Choose appropriate cartographic type.	3D representations and videos were chosen to be the appropriate cartographic type.
2. Develop		
2.1	Georeference and clip data.	This task involved cleaning the data for display in 3D through converting it to the correct format, georeferencing, and clipping the data to remove excess area.
2.2	Create 3D tracks.	This task involved creating a track by navigating through the 3D landscape.
2.3	Record the tracks as videos.	3D tracks were recorded into a video format for viewing outside of the ArcGIS environment.
2.4	Rework visualizations when necessary.	Visualizations were reworked if they were not approved upon testing. The client’s new specifications to change the maps were implemented. Testing continued until the visualizations met the client’s and advisor's expectations.

2.5	Provide support and tutorial documents to stakeholders and future project managers.	After the visualizations were created it was essential to provide users with help documents so they would be able to recreate or improve the project if necessary.
3. Deploy		
3.1	Deliver visualizations to the client.	After all QA and QC was completed visualizations were delivered to the client.
3.2	Implement visualizations in theater production.	The client was largely involved in this step because he decided how to best implement the maps into his theater production.
3.3	Review and confirm that client is able to utilize the products provided.	If the client required additional support to utilize the products he would be directed to the University of Redlands Center for Spatial Studies.

3.5 Summary

Various components were used to solve this problem. Several steps needed to be completed in order to visualize the data in 3D. First the data needed to be acquired from the USGS. Second the data needed to be formatted to create a 3D visualization. Navigation tracks needed to be created in ArcGlobe. Videos could then be recorded from the navigation tracks. These videos could then be displayed on a desktop monitor or projected onto a physical surface. Additional support documents were written so that Professor Beach would be able to use the products and so other project managers on the university campus can recreate the project.

Chapter 4 – Database Design

This chapter describes the data and database structure used to support this project. Section 4.1 outlines the high level conceptual data model. Section 4.2 describes the implementation oriented logical model. Section 4.3 describes the data sources in detail and provides appropriate metadata. Section 4.4 describes the data cleaning process that some of the image data had to undergo before they could be presented in 3D. This section also provides graphics and diagrams to aid in the understanding of the database.

4.1 Conceptual Data Model

A conceptual data model presents an abstraction of real world data. This is a human-oriented model of objects that are relevant to the domain of the problem. Figure 4-1 displays how this problem's essential components (sites, representations, and visualizations) relate to each other.

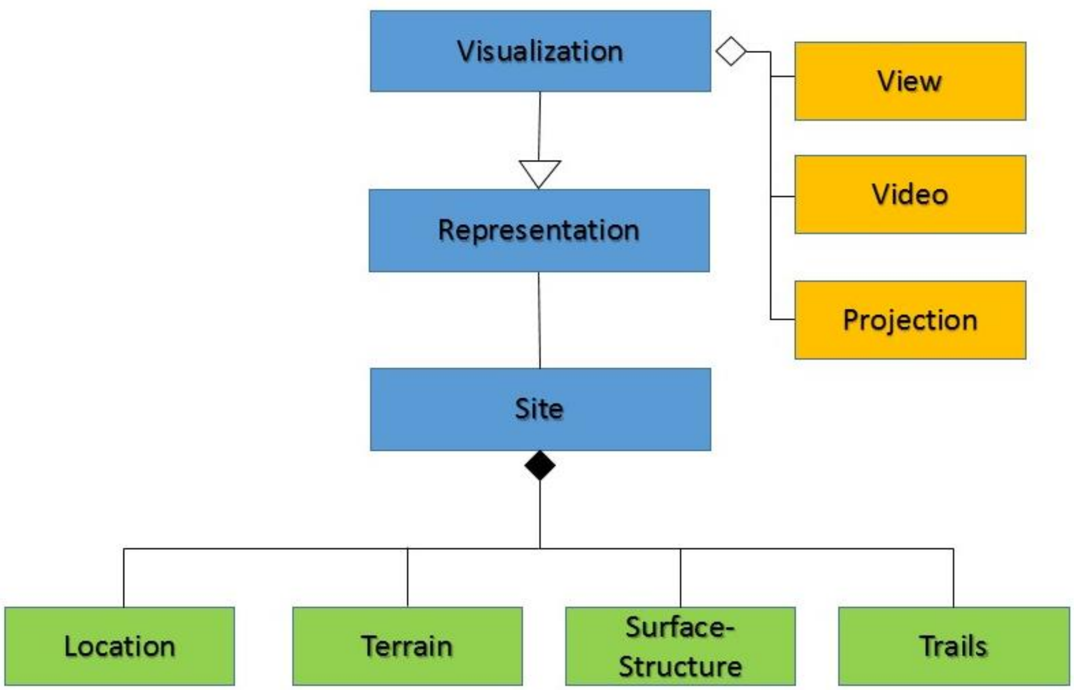


Figure 4-1: Conceptual Data Model

Each site was composed of geographic features such as mesas, mountains, stones and parking lots. These features were simplified for the 3D computer-aided representation. Terrain was represented by 10-meter resolution digital elevation models. Surface structure was represented by 1-meter resolution Geo JPEG files. Locations such as ruins or mountain peaks were represented by point features containing an x-coordinate (longitude), y-coordinate (latitude), and a label. Surface structure and locations received a z-value (elevation) because they were draped on top of the DEM.

The sites were collections of representations of real world components. Sites corresponded to areas of interest to this project such as the Canyon De Chelly National Monument, Sunset Crater National Monument, and Newspaper Rock National Monument. Because this project was implemented to visualize locations in a theater production, sites contained trails traveled and locations visited by characters in the play's story. Representation came from the various ways these sites were simplified. These sites were represented in 2D by USGS topographic maps, USGS orthographic photo imagery, Digital Globe orthographic imagery, ancient petroglyphs, and National Park Service brochures. The data were then represented in 3D. This 3D representation was then visualized through a video, 3D view, or projected on stage. The videos created were reinterpreted versions of the data created for the purposes of this project.

Real world features were simplified to digital data in the form of raster images and vector datasets. These data were represented in 3D through Esri's ArcGlobe software. Video fly-bys were created from the 3D representations. These videos served as one medium to convey the representations. Projections on stage during a performance served as another medium.

4.2 Logical Data Model

This section describes the implementation-oriented representation of reality for this project. The client was unfamiliar with ArcGIS software and would only use the AVI video files that were produced. These files were stored in a folder separate from the data that were used to create them, so that the video files may be easily copied to other machines, flash drives or DVDs as required. The video files can be transported without all of the data that were required to create them. The video files were exported using the Microsoft Video 1 format because it applies minimum video compression.

Sites are areas of interest such as tourist spots that the characters in the play visited in their story. All sites were contained in a folder separate from the folder containing videos. Each site was represented by a folder containing all data necessary to visualize that site and record a video. Sites were stored separately because during this project's implementation it became necessary to copy individual sites to alternate machines to test which machine could provide the most optimal means of recording a video. This allowed the sites' folders to be transported without having to copy the entire project to a new machine. Figure 4-2 displays this initial part of the database.

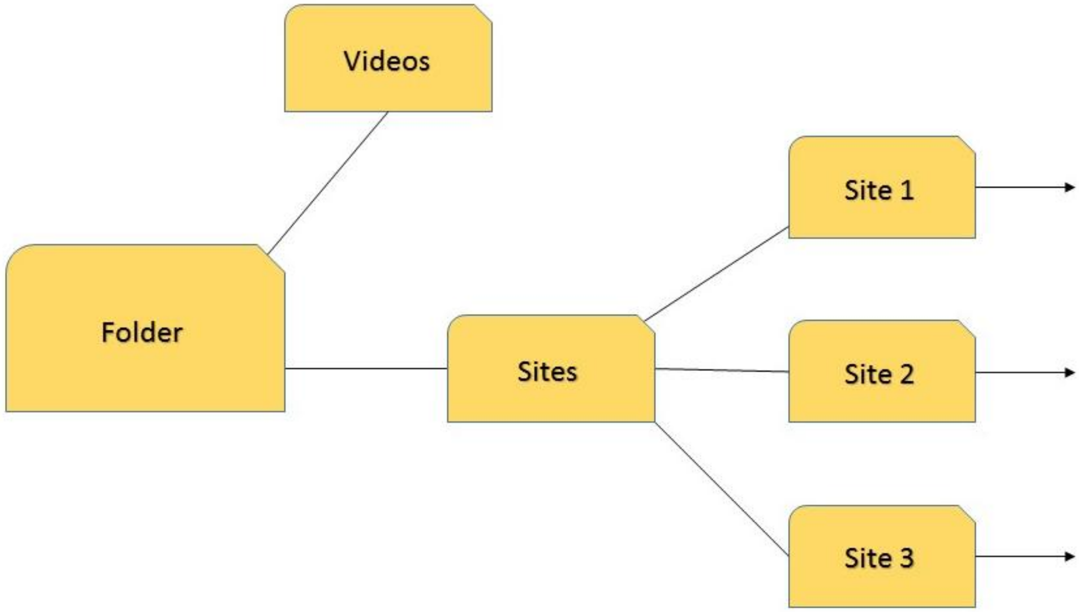


Figure 4-2: Logical Model Part 1

Each site folder contained the dataset necessary to both visualize the site and record a video. This included elevation and contained the digital elevation models (DEMs) for the site. The DEMs were one-third arc second resolution, or roughly 10 meter resolution. This resolution worked for this project because it provided the other data with appropriate elevation texture to be draped upon without slowing down navigation or making file sizes too large. Each DEM was stored in an Esri Geodatabase inside the corresponding site folder meaning each site had a geodatabase.

Each site folder also contained several georeferenced aerial orthographic photographs JPEG2000 format. These photographs represent the land’s surface structure. Each site contains a different amount of orthographic photographs depending on the area required to visualize the site. These JPEGs are in 1-meter resolution, which was appropriate because it allowed the data to draw smoothly during navigation and recording without sacrificing too much detail at higher perspectives or altitudes. These photographs were stored in the geodatabase in the corresponding folder.

Additionally some of the site geodatabases contained Orthographic imagery awarded from a Digital Globe research imagery grant. These data were 60-centimeter resolution GeoTIF files. These data provided higher resolution imagery when visualizations were viewed at a finer scale.

Each site folder also contained several stylized raster images that interpret the real world features in a different way. There is an eclectic mix of stylized raster images, such as historic USGS topographic maps, visitor maps from the National Park Service, and photographs of ancient petroglyphs that were georeferenced using ArcMap. Georeferencing data is explained further in Section 4.5. These representations were draped on top of DEMs in order to add elevation texture and stored in the geodatabase in the corresponding site folder, together with the corresponding DEM and the orthographic photography.

Each geodatabase within each site folder also contained an Esri .3dd file that corresponds to the site. A .3dd file is similar to an Esri .mxd file but for 3D documents. It stores the perspective and layout of a 3D visualization when saving the document. This was useful for having all data in the site quickly display as intended. For the purposes of this project the .3dd format allowed raster images to be draped upon DEMs with the correct vertical exaggeration in the correct order as soon as the .3dd was opened. This allowed videos to be quickly recorded upon opening the .3dd without needing to manipulate the data first.

The final object stored in the site folder was the animation file. The animation file cannot be stored in a geodatabase so it must be contained within a separate folder inside the main site folder. An animation file contained keyframes necessary for playing and recording an animation track in ArcGlobe. A keyframe is a snapshot of a layer's properties, such as perspective and altitude. Animations can be loaded into the animation toolbar and then exported to create videos. Figure 4-3 shows the data that are inside each site folder.

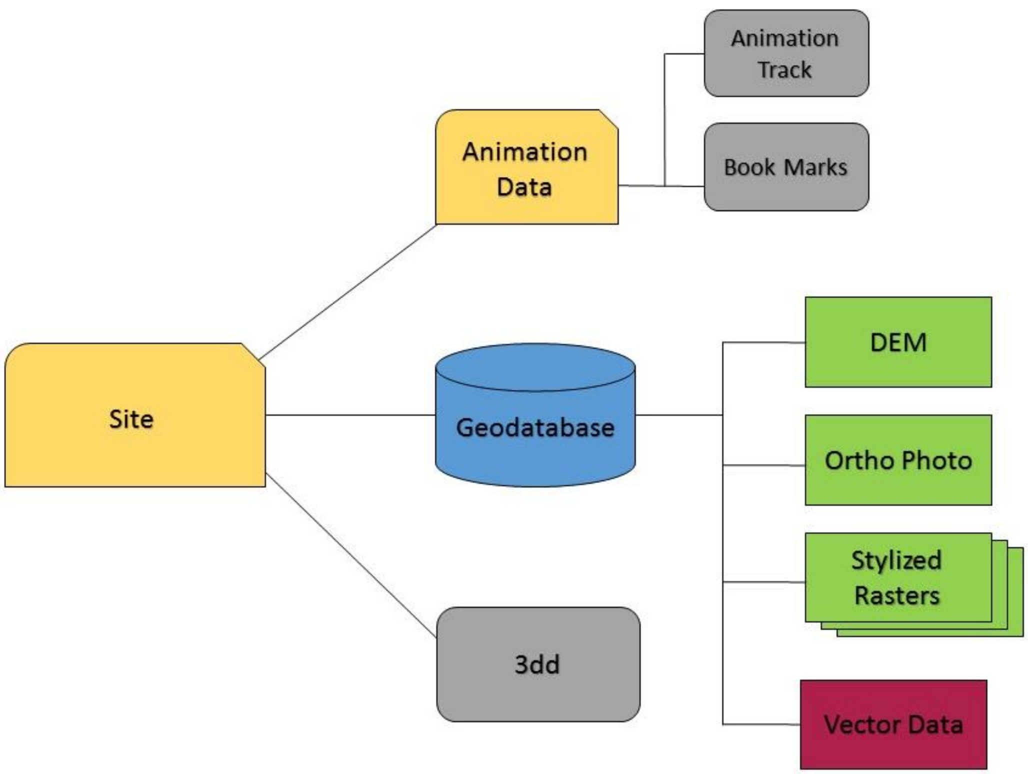


Figure 4-3: Logical Model Part 2

All data pertaining to a site were stored in a separate folder from other site data to make data copying and transportation easier. All data serve the purpose of creating a video that can be displayed in the client's production.

4.3 Data Sources

The majority of the data used in this project were acquired from the USGS. The USGS website provided the DEMs, orthographic photography, and historic topographic maps. Other stylized raster images were downloaded from other online sources. Digital Globe provided orthographic imagery data from an imagery grant. The client provided the names of the sites he wanted to include in the project, and also identified a book called *Where the Rain Children Sleep* by Michael Engelhard. This book provided more site names, as well as descriptions of trails.

The USGS DEMs are distributed as 1x1 degree section ArcGrid raster datasets. They are tiles of the National Elevation Dataset (NED) and are in one-third arc-second resolution. NED served as the elevation layer of The National Map, and provided basic elevation information. These data were distributed in geographic coordinates in units of decimal degrees, and on the North American Datum of 1983 (NAD 83). All elevation values are in meters. The DEMs were downloaded using the bounding box feature on the USGS data download page. They were selected because they encompassed the sites referenced in the performance. A DEM is shown in 2D in Figure 4-4.

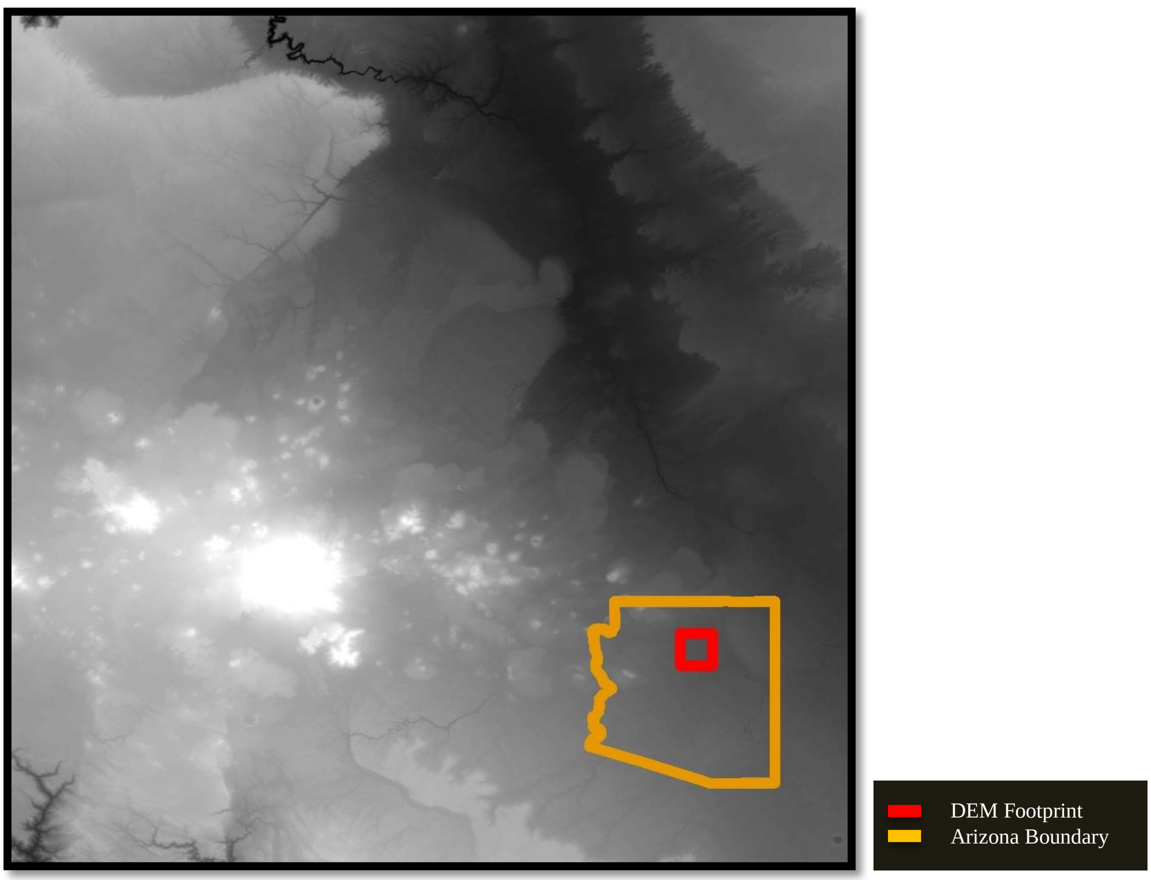


Figure 4-4: San Francisco Mountains, Arizona DEM

Several orthographic image data sources were considered when gathering data for this project. The one meter resolution USGS orthographic photos were downloaded in the

JPEG 2000 (JP2) format, an image compression standard and coding system. The photos came pre-georeferenced from the National Agriculture Imagery Program (NAIP), which is administered by the United States Department of Agriculture. The NAIP acquisition cycle is based on a minimum three year update of base orthographic imagery. The tiling format of the NAIP imagery is based on a 3.75' x 3.75' quarter quadrangle with a 300 pixel buffer on all four sides. The 60-centemeter resolution orthographic imagery was acquired from a Digital Globe Foundation imagery data grant. These data were in GeoTIF format. The Digital Globe dataset was composed of about 820 square kilometers of several different images to make up each site. In total the Digital Globe dataset was 36 gigabytes of imagery and took about four hours to download onto a local hard drive. The area of the imagery was drawn from bounding polygons provided to the Digital Globe Foundation during the grant's request (Figure 4-5).

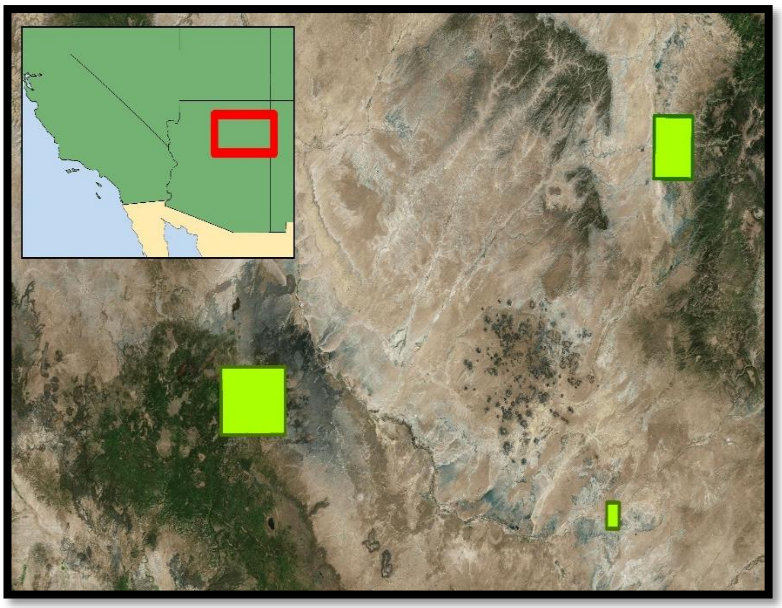


Figure 4-5: Bounding polygons for requested Digital Globe imagery data

Thirty centimeter ArcGIS base map imagery was considered for use in this project, but this imagery could not be cached and used in a 3D video. All three image sources are compared through depicting a cliff in the Canyon De Chelly National Monument in Figure 4-6.

1 meter
resolution imagery

30 centimeter resolution imagery

Figure 4-6: Imagery resolution comparison

The topographic maps were downloaded from the USGS website (http://viewer.nationalmap.gov/viewer/) in the GeoPDF format. The USGS Historical Quadrangle Scanning Project (HQSP) scans all scales and all editions of topographic maps published by the USGS since the inception of the topographic mapping program in 1884. This map is provided as a general purpose map in GeoPDF format for display by users who are not GIS experts. Figure 4-7 displays a downloaded topographic map.

Figure 4-7: 1894 San Francisco Mountains Topographic Map

The 60-centemeter resolution orthographic imagery was acquired from a Digital Globe Foundation imagery data grant. These data were in GeoTIF format. The area of the imagery was drawn from a bounding polygon provided to the Digital Globe Foundation as a part of the grant application.

The National Park Service maps were downloaded in PDF format from the National Park Service website (http://www.nps.gov/hfc/cfm/carto.cfm). These maps are designed to be used for recreational purposes and used by individuals who are not GIS experts. They display tourist attractions and other recreational facilities. The National Park Service maps are displayed as downloaded in Figure 4-8.

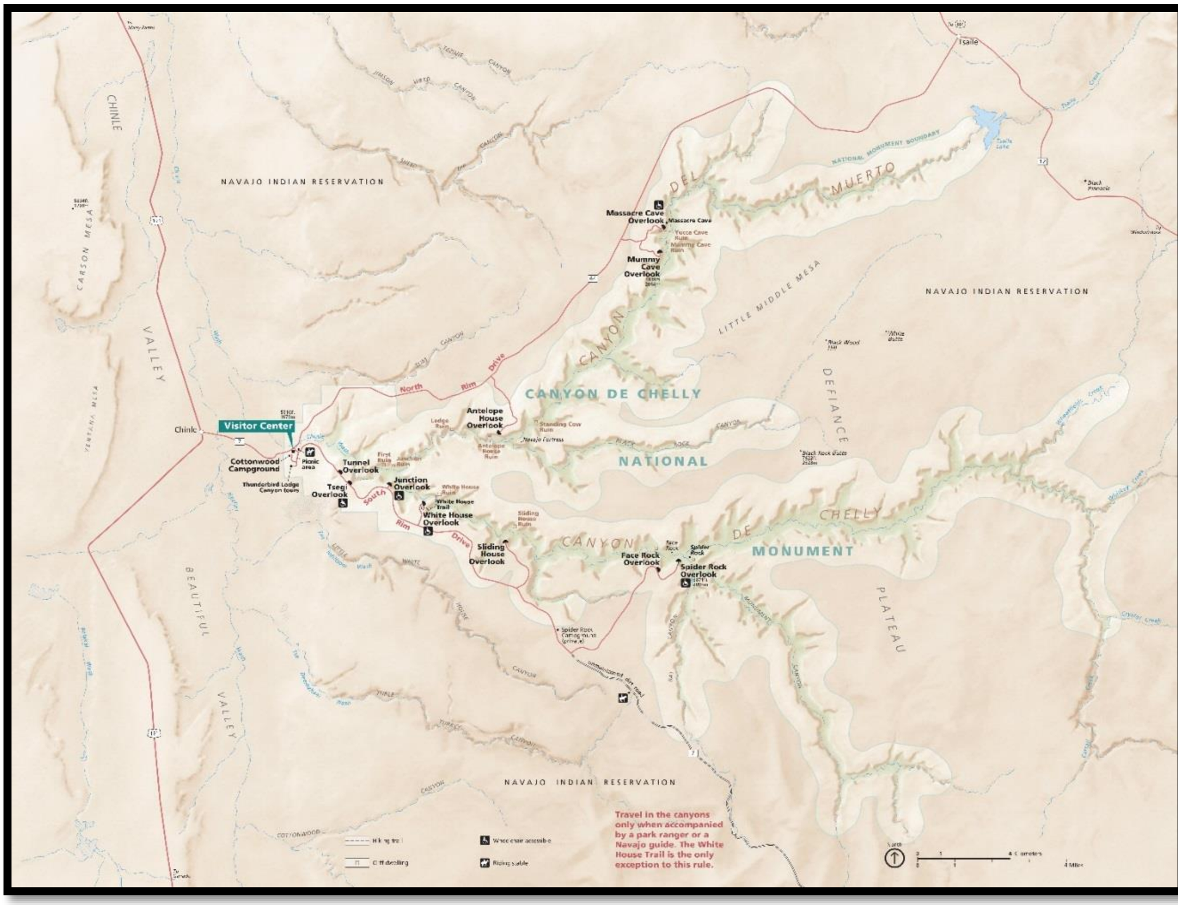


Figure 4-8: Canyon De Chelly Park Visitor Map

4.4 Data Scrubbing and Loading

In order to display PDF format files such as the historic topographic and National Park Service maps, it was necessary to convert these files to JPEG format. To do this the PDF maps were imported into Adobe Photoshop in 600 DPI resolution. They were then saved in JPEG format with the maximum image quality option.

After the images were converted to JPEG format they were georeferenced in ArcMap 10.2.2 with the spatial reference of GCS_North_American_1983 using the coordinates at the corners of the map if they were available. If coordinates were not available the images were georeferenced using common control points to the Esri USGS base map.

When displaying the high resolution GeoTIF files acquired from Digital Globe it was necessary to have the DEM and imagery spatial reference line up directly for display in 3D, this meant that the DEM needed to be repreojected using the project tool in ArcMap. The USGS DEM’s spatial reference was changed from GCS_North_American_1983 to WGS_1984_UTM_zone_12N.

4.5 Summary

This chapter described the structure of the data and how all data relate to each other to support the project. The data are abstractions of reality used to communicate a message about the landscape. In this case the mediums are views, videos and projections on the stage.

Chapter 5 – Implementation

This chapter reviews this project's implementation by describing each component and each decision made to create the final product. Section 5.1 describes how each site was pieced together and displayed at the highest possible quality. Section 5.2 describes how vector symbology was implemented and how choices in symbology played an important role in this project's cartographic representation. Section 5.3 explains how the unique subproject of the Shavano Valley petroglyph was implemented. Section 5.4 describes how the animation tracks were created and then exported to video format. Section 5.5 reviews each of the unsuccessful methods that were partially implemented but were ultimately unable to satisfy this project's requirements.

5.1 Creating the Scene

Creating each scene first involved georeferencing image data and required elevation layers to be properly set and implemented. Finally the image data needed to be cached in order to display quickly at full resolution during the animation fly-throughs.

5.1.1 Georeferencing

In order for the data to be displayed in 3D it was first necessary to georeference data that contained no spatial reference. Georeferencing raster data involves defining their location using map coordinates and assigning the coordinate system of the data frame. This allows the raster data that previously contained no spatial reference to be viewed and queried alongside other spatial data. The spatial reference used while greoreferecing these data was GCS_North_American_1983. This spatial reference was used because the data acquired from the USGS were referenced using GCS_North_American_1983. Coinciding spatial references made data integration seamless.

Georeferencing could only be completed in ArcMap because there is no georeferencing tool in ArcGlobe. In ArcMap 10.2.2 georeferencing is accomplished by first loading a raster image with no spatial reference into the data frame and opening the Georeferencing Toolbar. The user can then create control points that connect points on the raster image with known spatial coordinates. This can be accomplished by either inputting latitude and longitude coordinates directly into the control point or by selecting a point that exists on the un-georeferenced raster image and a corresponding spatially referenced point that exists in a feature. The control points can then be saved. For the purposes of this project both methods were used depending on which raster image required spatial reference. Some raster images had latitude and longitude points embedded in the imagery. This allowed for the input of coordinates directly. For example the USGS topo map from 1896 had coordinates embedded in the imagery. Georeferencing the historic USGS topographic map came with an extra set of difficulties. The map's datum was unknown so the features are slightly inaccurate. Without knowing the map's true datum the georeferencing cannot be completely accurate.

Other raster images did not have these coordinates, which meant they had to be connected through control points with datasets that had known spatial references. A certain number of control points are required to complete a transformation. The georeferencing toolbar in ArcMap has a function that lets the user control the transformation used to georeference the data. Transforming−or warping−the raster dataset permanently matches the map coordinates of the target data. Most of the georeferenced raster images were transformed using the first order polynomial option. On average four to five control points were used because only three control points are required to complete a first order polynomial. Increasing the number of control points means more errors are introduced in a first order polynomial transformation. Transformations are further discussed in section 5.3.

Once a raster image has a sufficient number of control points the transformation can be saved to the existing raster image or to a new dataset with the *rectify* option. The rectify option creates an entirely new raster dataset in the coordinate system of the current data frame. The rectify option was used on all of the raster images in order to create new datasets without altering the original ones. By georeferencing the data that contained no spatial reference, raster images can be viewed alongside other data that have a spatial reference. This also allows the raster images to be draped on an elevation model.

5.1.2 Elevation

Elevation data are essential in the visualization of 3D landscapes; they add texture to the landscapes to make them look 3D. USGS DEMs were used as elevation data sources for the purposes of this project. When a DEM is brought into ArcGlobe, the software recognizes that it is usable as elevation data. The software opens a dialogue box prompting the user to choose whether the DEM should be used as an image source or an elevation source. If the DEM is chosen as an elevation source it provides surface height values for other layers. The elevation layer will have no visible symbology. When other features are loaded into ArcGlobe they are draped on top of the elevation dataset if both raster datasets share a spatial location. The elevation source of a feature may also be selected from the properties menu.

Vertical exaggeration is another feature that can be manipulated in ArcGlobe and is used to emphasize subtle changes on the earth's surface. Vertical exaggeration is used in 3D cartography to emphasize elevated features in a large area. For example the entire Sunset Crater topographic map covers an area of 1 x 1 degree in longitude and latitude. With this large area, mountainous terrain is not very prominent in a 3D scene. However, when vertically exaggerated by a factor of 3 the mountainous terrain stands in stark contrast to the rest of the terrain (Figure 5-1).

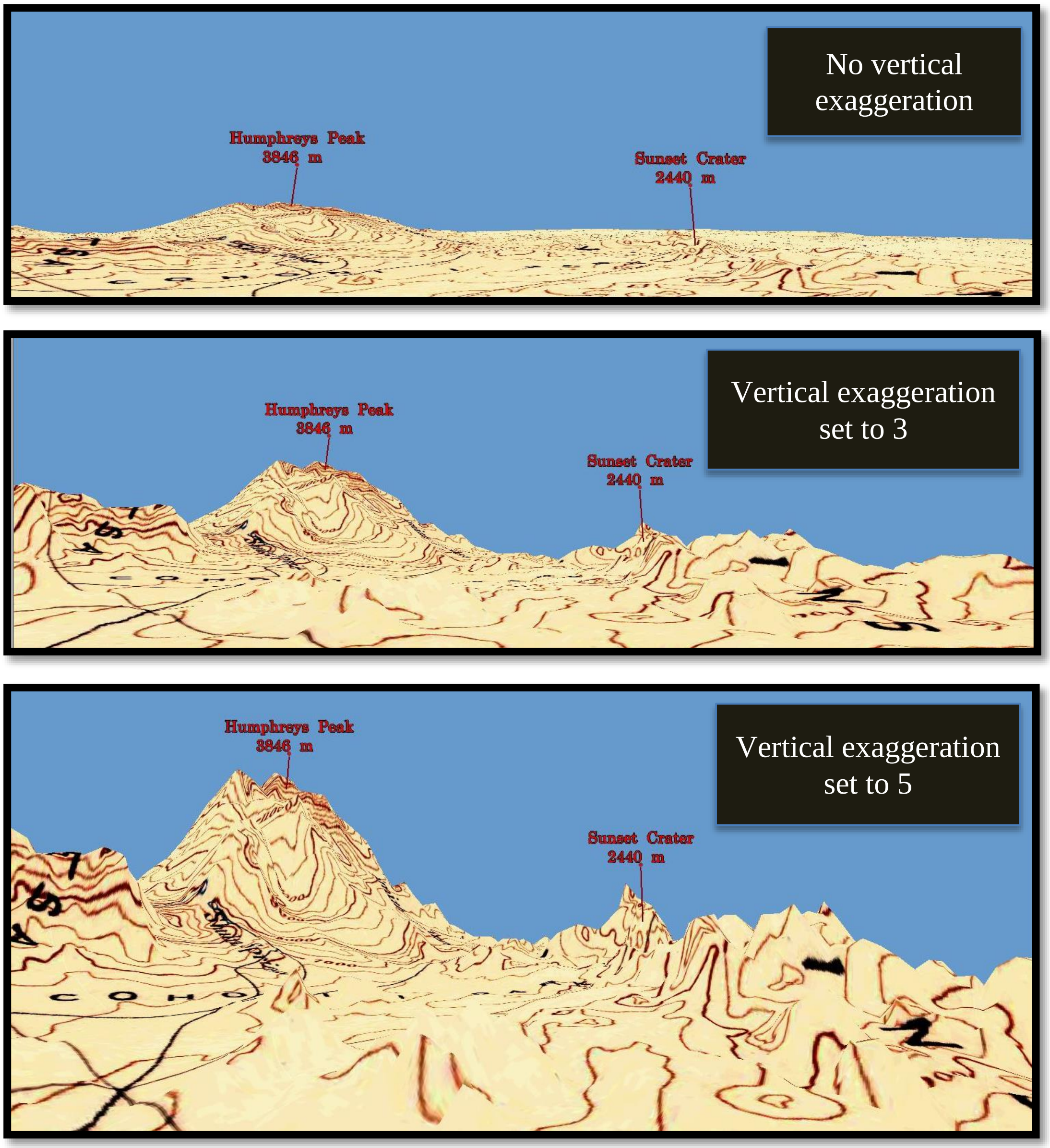


Figure 5-1: San Francisco Mountains with vertical exaggeration at different settings

The Canyon De Chelly Visitor map scene was vertically exaggerated by a factor of 2 to emphasize the canyon's terrain. The same thing was done in the Shavano Canyon petroglyph scene. When working with abstract visualizations like topographic maps, petroglyphs, or visitor maps it is important to vertically exaggerate features to a noticeable extent. This makes the data look 3D and highlights any terrain contrasts that are needed to understand the map.

Another customizable elevation option that exists in ArcGlobe is Level of Detail (Figure 5-2). This alters the level of detail that is drawn from the DEM. At the highest level of detail the DEM will be used at its full one-third arc second resolution. This image was customized to show the highest level of elevation detail.

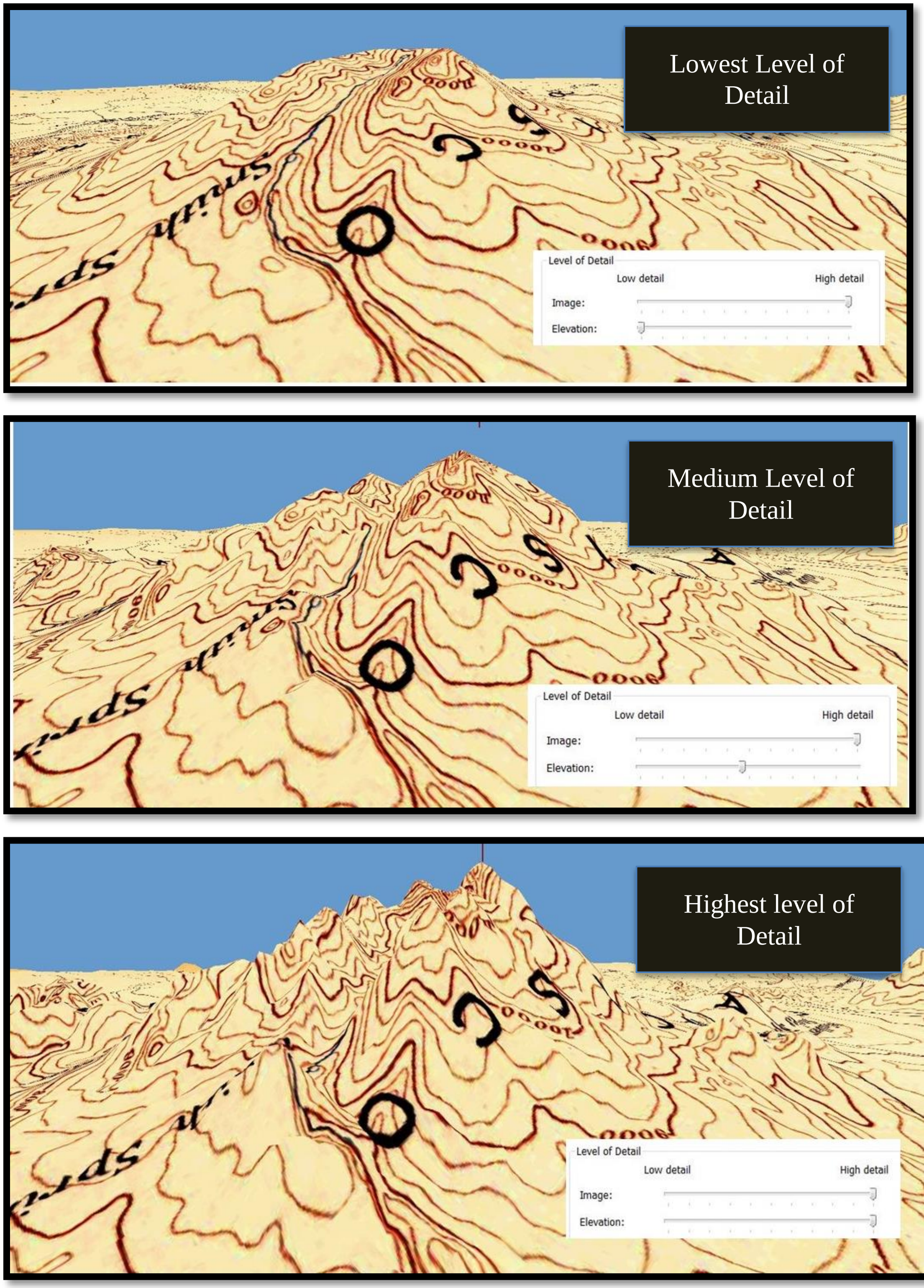


Figure 5-2: Levels of detail

5.1.3 Caching

In order to display the data at full resolution while navigating and recording videos, it was necessary to fully cache the data. A cache will generate the image at full extent and resolution at every scale. This means that the user can navigate anywhere in the scene at any scale and the cache for that view has been generated. The layer will render as fast as possible after it is cached. This allows for fast and full visualization of the data on the screen. This is especially important when recording high quality videos. In ArcGlobe caches are usually created automatically and data are cached depending on where the user navigates and the on screen scale. However, fully caching layers assures that the cache exists for the entire layer.

No lossy compression was applied to the layers within this project. A lossy compression reduces the quality of a video reduce file size. Without a lossy compression, images appear in their original form without any resolution loss through compression. This project required the data to be displayed at the highest resolution possible. An example of the cached imagery is seen in Figure 5-3, the cached Canyon De Chelly visitor's map draped upon a DEM.

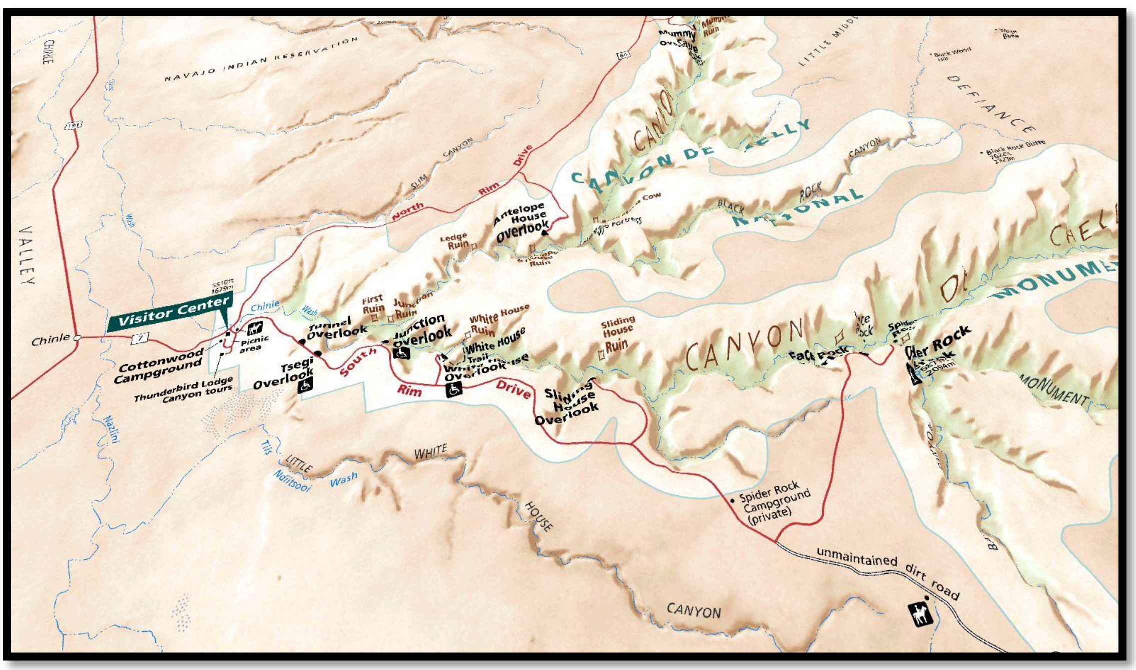


Figure 5-3: Cached Canyon De Chelly visitor's map

5.2 Vector Symbology

Vector symbology was implemented to label important features such as peaks and ruin locations. Vector symbology was also used to illustrate the White House ruins at the Canyon De Chelly National Monument.

5.2.1 3D Labels

Three dimensional labels were created by labeling point feature classes. Point feature class data for the Sunset Crater site were exported from the USGS peaks dataset. Only seven peaks were chosen to be exported from the original dataset. This is because if all peaks included in the dataset were displayed the site would look cluttered (Figure 5-4).

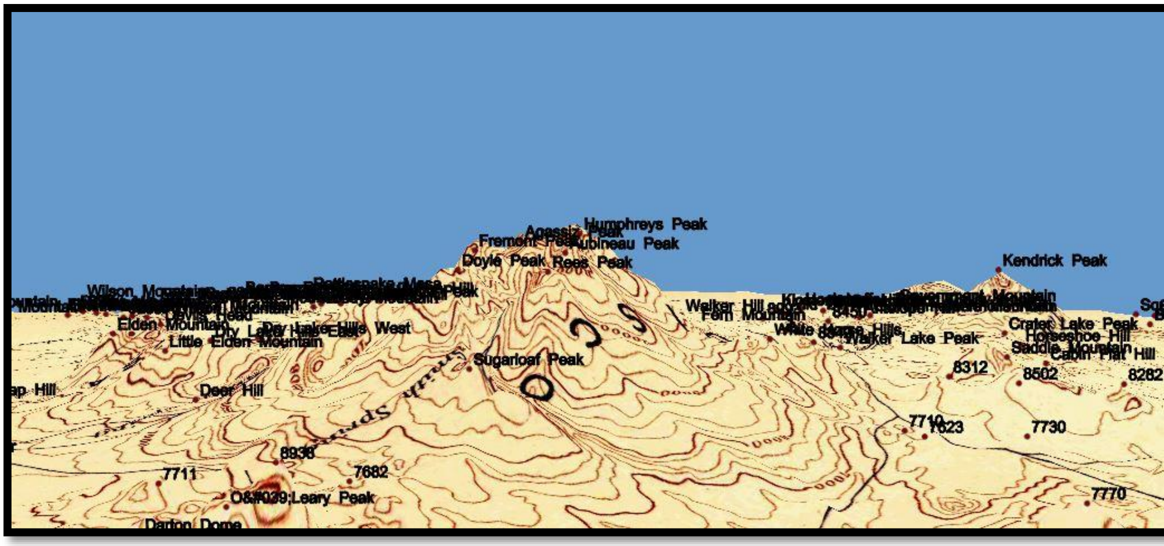


Figure 5-4: Cluttered peak labels

The peaks that appear in the final product were selected because they were referenced in the book *Where the Rain Children Sleep* (Engelhard, 2004). These peaks were also exported twice to create two sets of the peak feature class. This was done so one set of peaks can display the labels and the other set of peaks can serve as the extruded poles.

After the selected peaks were exported they were then displayed as 3D vectors within the document. This was because the points needed to have 3D symbology. This also allowed their height above the globe surface to be manipulated. The first set of peaks was positioned 1500 meters above the globe surface so that they were prominent within the site but were not so high they no longer appeared to have a connection with their location on the surface. The pole points were extruded to 1500 meters above the globe surface to coincide with the label points that were positioned at the same altitude. The peak label sql expression was learned during a personal communication with Esri 3D GIS engineer Nathan Shephard. This sql expression was used to display elevation data within the labels:

[Name] & vbcrlf & [Ht_meters] & " m "

In the sql expression “[Name]” displays the peak name present in the “Name” attribute feild. The command “vbcrlf” (visual basic carriage return line feed) forces a new line in a string allowing the peak’s elevation data to be displayed below the peak’s name. “[Ht_meters]” displays the peaks height in meters which is present in the “Height” attribute feild and ‘“m”’ displays the character “m” to indicate that the height is in meters.

The poles link the labels to the mountain peaks on the globe surface. This makes it easier to see which label represents which peak. The labels were then represented in bold, mars red, 14 pt. font, directly above their corresponding point (Figure 5-5).

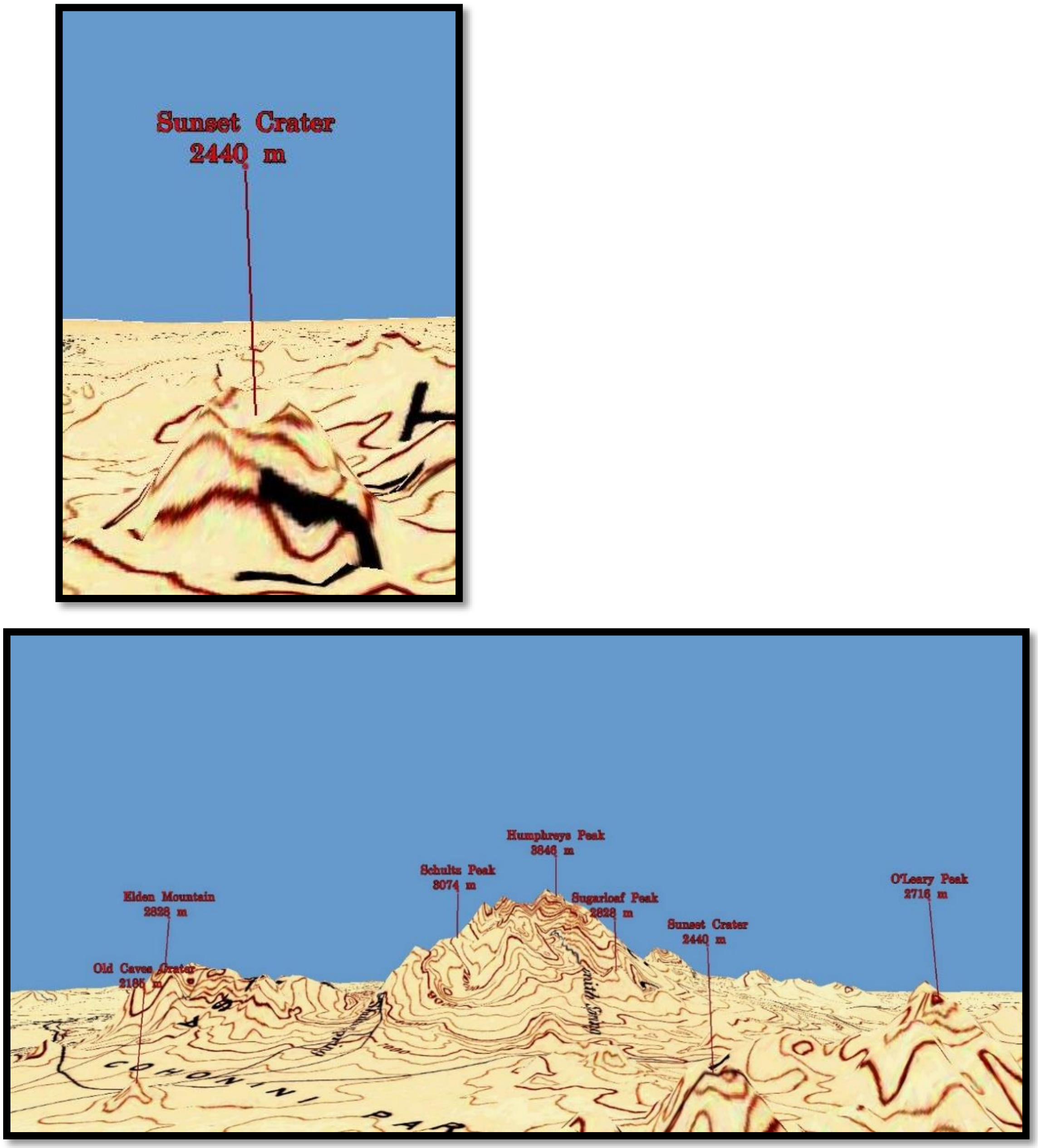


Figure 5-5: San Francisco peak labels; individual label (top) and group of labels (bottom)

Sometimes when the symbology of the label was manipulated–such as font position, size or even color–the labels would not display. In order to display data with their new symbology, the ArcGlobe application was shut down and reopened. This appears to be an intermittent bug in the software.

5.2.2 Canyon De Chelly Wall Symbology

This project required representation of the White House Ruins at the Canyon De Chelly National Monument. The ruins do not appear in the USGS imagery because the imagery is collected from an orthographic perspective and the ruins exist under a cliff. The solution was to symbolize the ruins using a point feature which was symbolized with a photograph of the ruins.

A point feature was digitized 5 meters south of the cliff where the ruins exist. By doing this, the billboard vector symbology did not overlap the slope of the cliff (Figure 5-6). The point was then offset 30 meters from the globe's surface so it was located at an elevation halfway up the cliff. In the symbology tab of the point feature the symbology type was changed to *3D Marker.* The photo of the White House ruins was selected as the 3D marker. The option *Display Face Front* was turned off. This ensured the marker would not follow the viewer while navigating and is locked in place on the cliff wall. The size was set to 100 meters to coincide with the cliff features that are being symbolized. Finally X rotation was set to 90° to make the image upright.

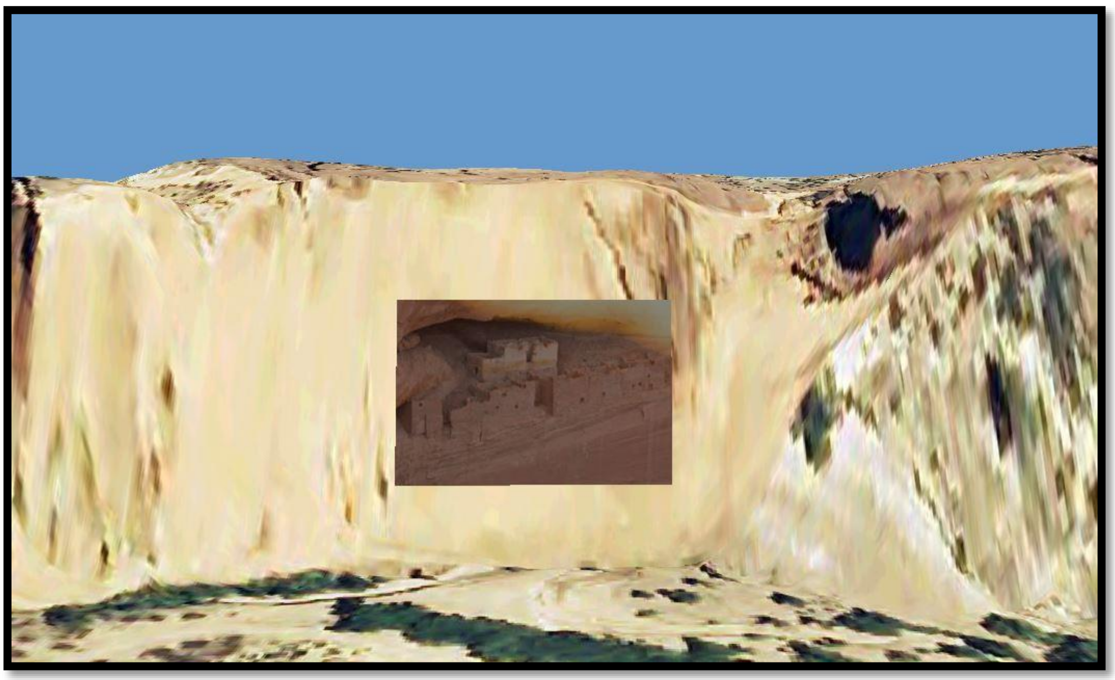


Figure 5-6: White House Ruin symbology

5.3 Georeferencing the Shavano Valley Petroglyph

This project required an image of the Shavano Valley petroglyph to be georeferenced. This image had no spatial reference and no coordinates to accompany it, so it needed to be georeferenced by manually adding control points. Thirty-four control points were used to georeference the image. The initial control points were drawn from Carol Patterson's article *Ute Indian Rock Art Maps and Game Drives in Western Colorado* (2007). This article provided geographic areas that the petroglyph shared with the USGS topo map. Figure 5-7 shows points on the petroglyph image that correspond to real world features.

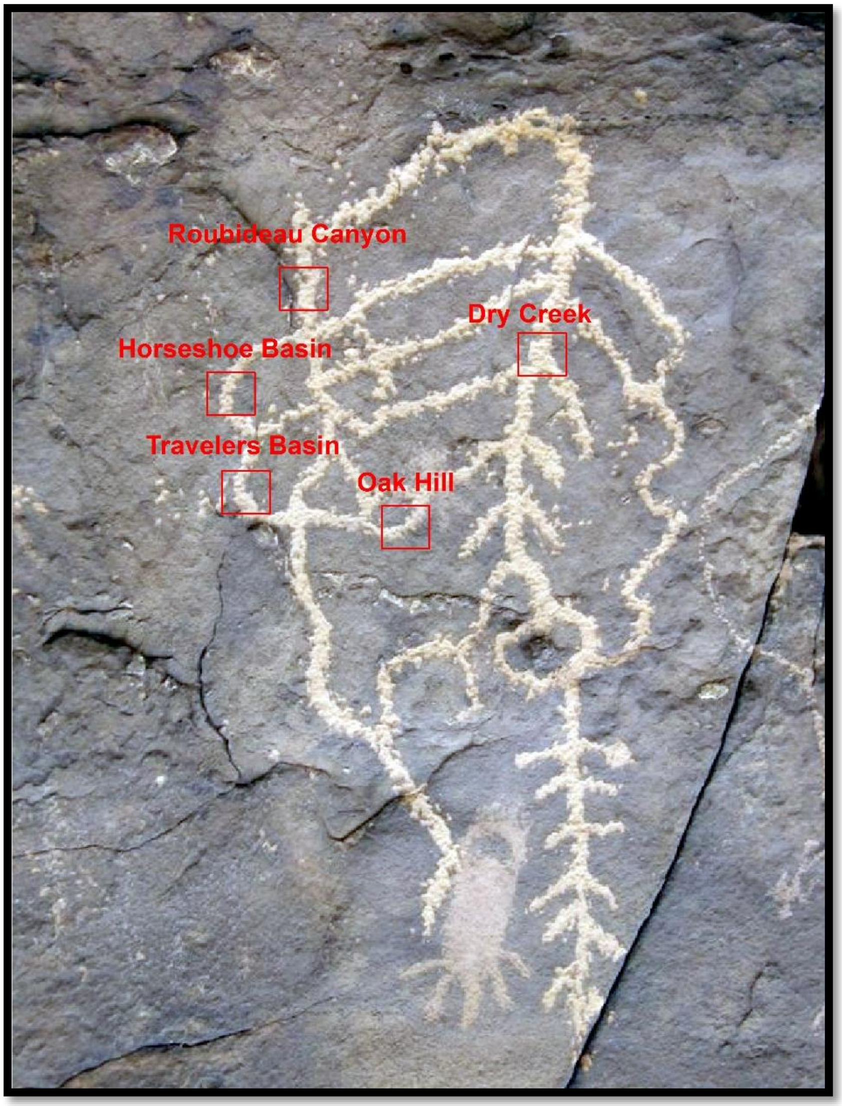
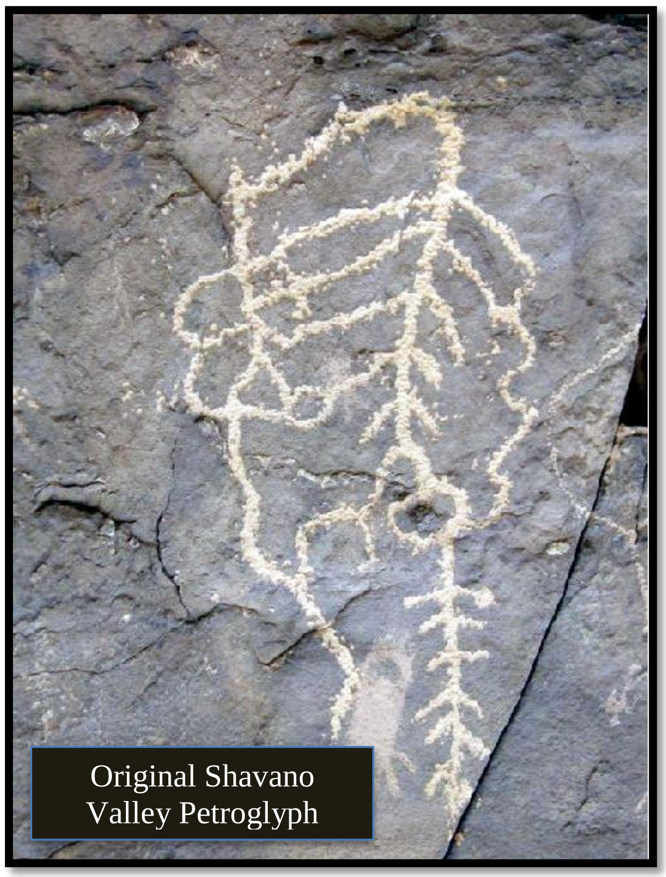


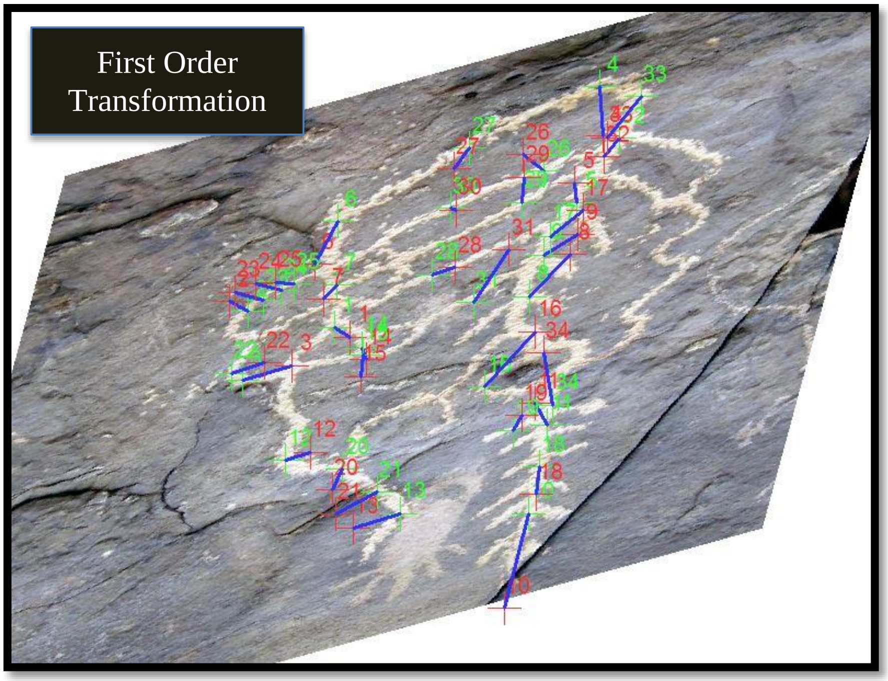
Figure 5-7: Initial Shavano Valley petroglyph control points adapted from Patterson 2013

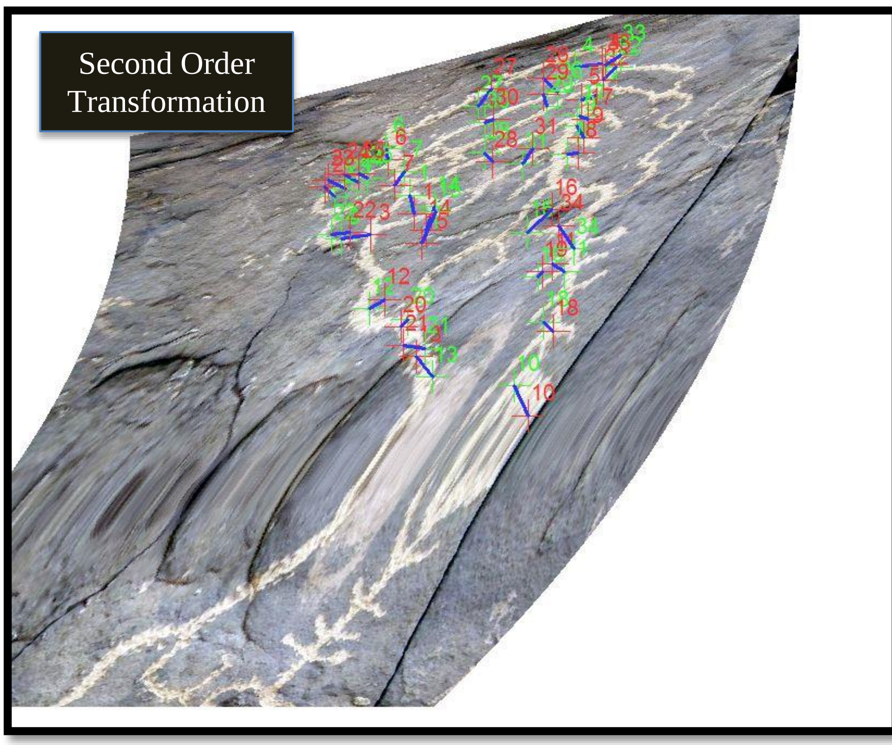
Patterson's study required her to do little to warp the petroglyph image to coincide with real world coordinates. Instead the petroglyph was overlayed on the USGS topographic map to show similarities in topography. For the purposes of this project it was necessary to rubbersheet the image to fit the topography. This is because the petroglyph image needed to coincide with the elevation data provided by the DEM in order to be displayed in 3D properly. The remaining control points were selected based on hydrography and elevation data because the petroglyph displays hydrography and elevation features.

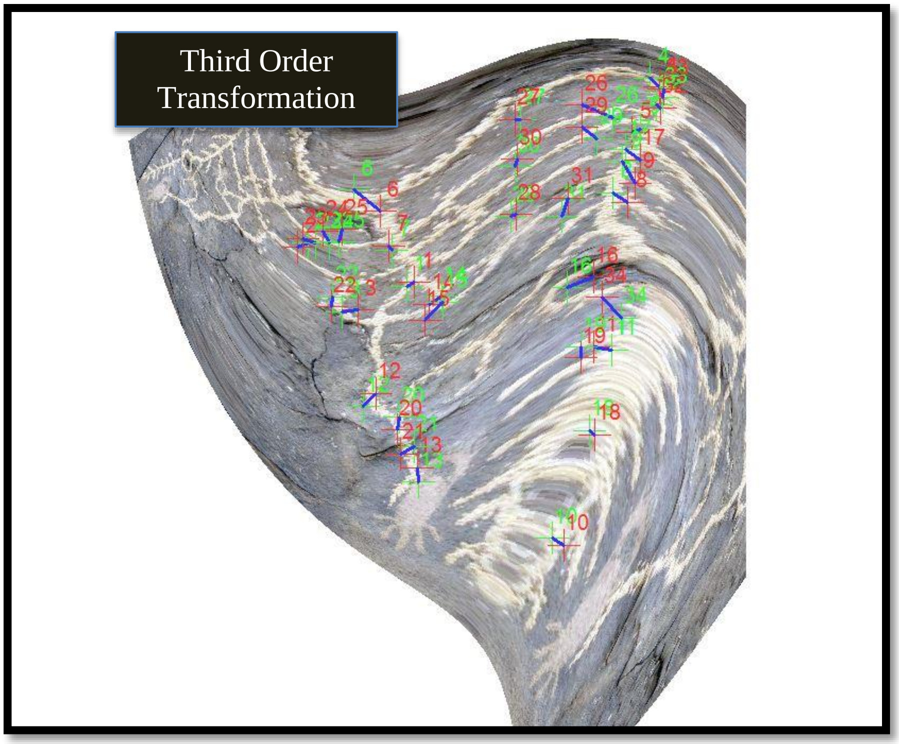
After the first ten control points were selected, the transformation method was changed to spline in order to better rubber sheet the image to the real world features. The spline transformation was chosen because it is a true rubbersheeting method and optimizes local accuracy. It is based on a spline function, a piecewise polynomial that maintains continuity and smoothness between adjacent polynomials. This ensures that the image is still recognizable even after significant warping. Spline transforms the source control points exactly into target control points. It does not maintain points in their exact location but that is not necessary because the petroglyph image is a very abstract representation of the terrain. Adding more control points to this type of transformation can greatly increase accuracy.

Other transformations did not sufficiently warp the image. The first-order transformation was useful for setting the initial control points but did not allow the image to warp enough. The higher order transformations warped the image so much it became unrecognizable. The spline transformation proved to be the most useful for this project (Figure 5-8).




First Order
Transformation


Second Order
Transformation



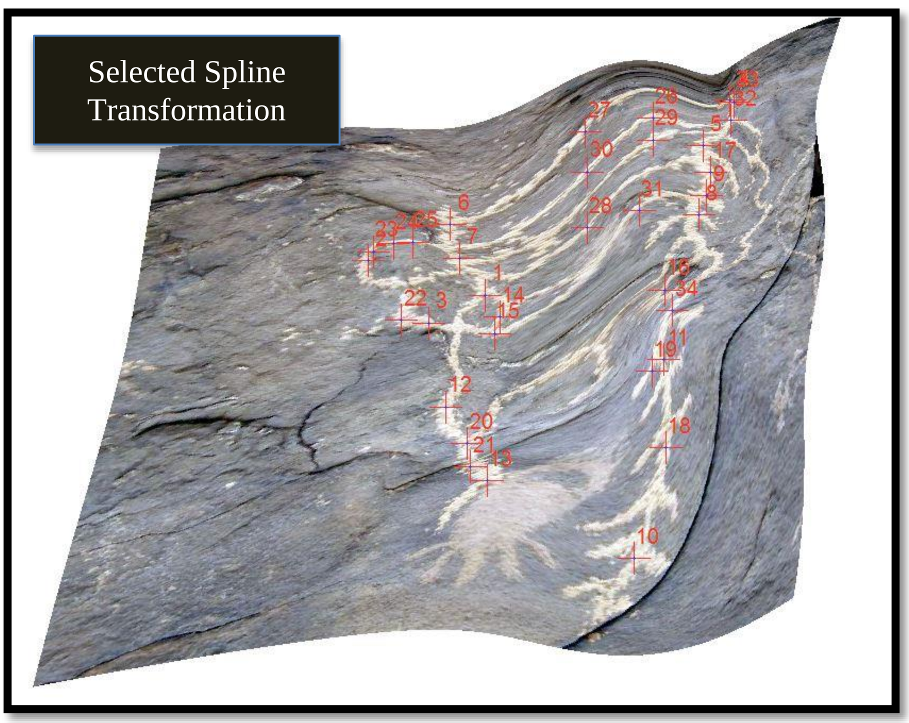


Figure 5-8: Georeferencing Transformations

After the petroglyph image was properly georeferenced it was draped upon a DEM to be displayed in 3D (Figure 5-9).

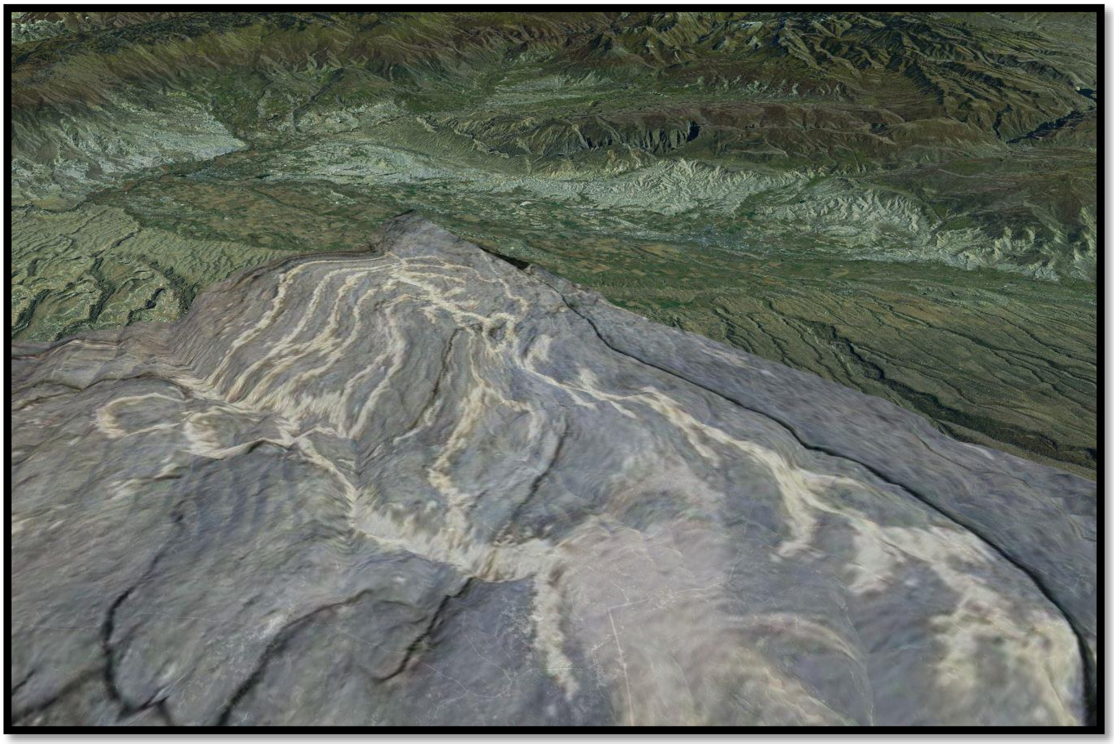


Figure 5-9: Shavano Valley petroglyph draped image

5.4 Recording Videos

Once each site has been assembled animation tracks could be created. These animation tracks could then be exported as a videos.

5.4.1 Animation Tracks

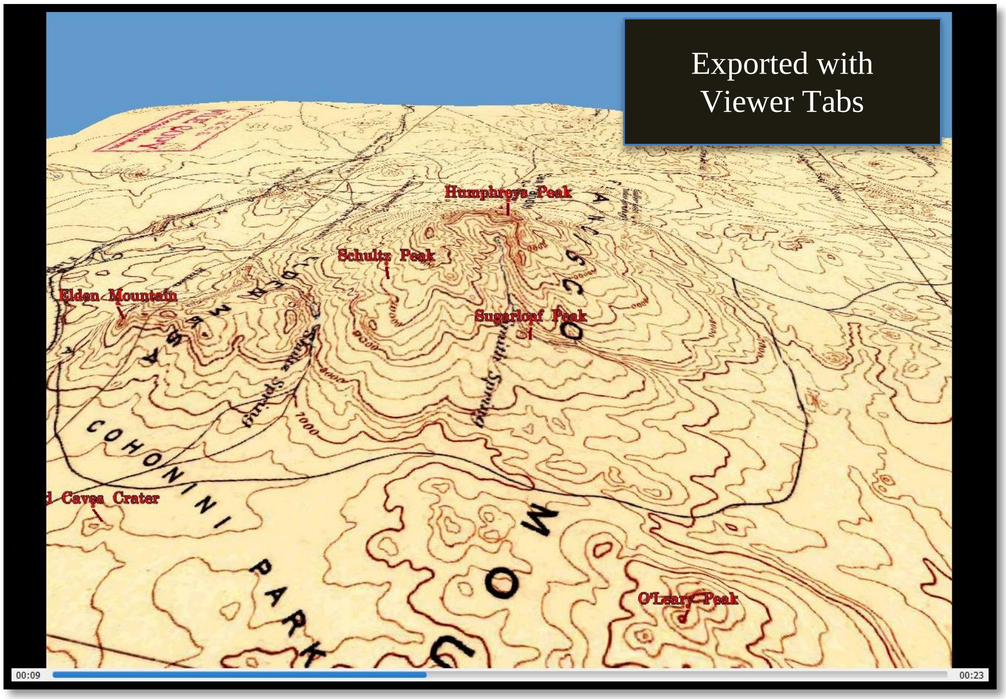
To begin creating an animation track, geospatial bookmarks or places of interest were created. Bookmarks save a camera perspective and can be used to zoom to a particular location and perspective at any time. Several bookmarks were created for each site to record their respective videos. These bookmarks were converted into keyframes using the animation toolbar. A keyframe is a snapshot of an object's properties at a certain time during the animation. Animation tracks are made up of keyframes. The camera moves from one view to another based on keyframes. Keyframes can be manipulated using the animation manager. With the animation manager it is possible to set the order in which the keyframes appear and also the speed at which the camera moves from one keyframe to another. It is also possible to create group layers. A group layer is an animation that loops sequentially through the series of layers. This allows layers to turn on and off while implementing a fly-through animation. This technique was used in the Newspaper Rock site to switch between the USGS topographic map and the orthographic photography. The animation was set to fade between the layers to ensure a smooth transition.

Animation tracks were created using this method for each site. Creating keyframes from bookmarks proved to be the easiest, smoothest, and most precise way to create animation tracks for this project.

Once an animation track is created, the speed at which the track plays and the frames per second (FPS) can be managed. The duration of the track can be set to make the track play for however many seconds were set in the manager. Along with this the number of frames that exist in the track can be set. More frames will make the animation appear smoother because it will transition through more intermittent frames. Less frames will make the track appear jittery because the track will alternate between less frames and each transition will appear more abrupt. Three hundred frames were used for every 10 seconds of track. This allowed the animation to appear smooth while moving at a sufficient pace.

5.4.2 Exporting Videos

After the animation tracks were set as required, the tracks could be exported as video files. In order to export the videos with the widest frame width, all extraneous windows were removed from the ArcGlobe viewer including the table of contents and the ArcCatalog windows. Closing tabs while exporting videos caused a significant difference. A video recorded with all tabs removed had a frame width of 1888 pixels, while a video with the tabs open had a frame width of 1224 pixels. The video with the longer frame width also had a larger file size with 781MB verses the video with a shorter frame width with a file size of 498 MB. All other settings in each video file were the same (Figure 5-10). The figures depict the same video at the nine second mark but the graphic extent is visibly different.



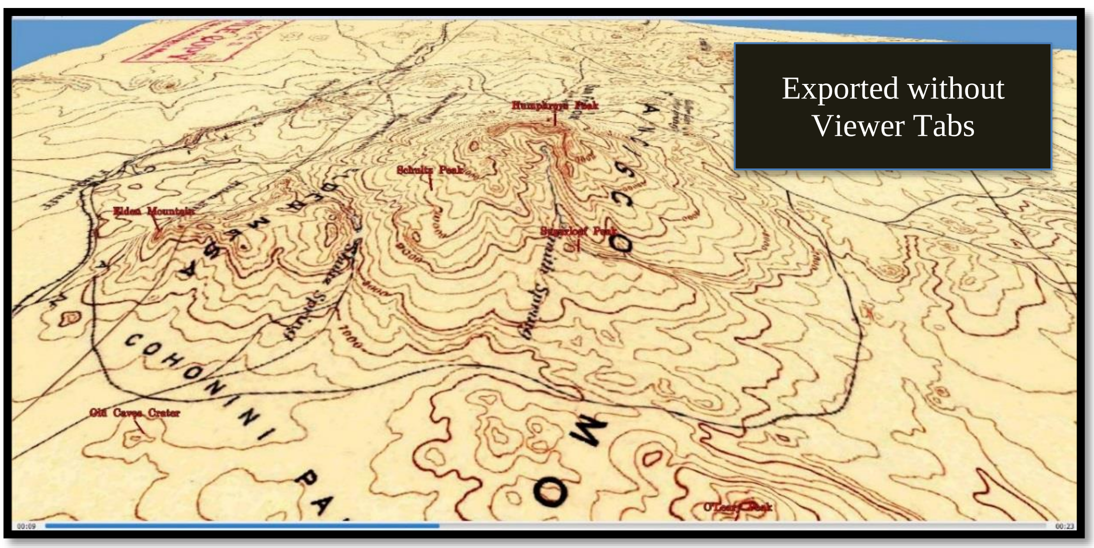


Figure 5-10: San Francisco Mountains video exported with viewer tabs open and viewer tabs closed

The videos were exported in the default Audio Video Interleaved (AVI) format. The compressor chosen was Microsoft Video 1 with the temporal quality ratio set from the default .75 to 1. The temporal quality ratio controls the smoothness of the transition from frame to frame. With the temporal quality ratio set to 1, the video is significantly less jittery.

Compression quality is also set to maximum. This assures that minimum quality is lost when compression is applied. With the full frames option no compression is applied but the video is on average about three gigabytes instead of about 800 megabytes and unplayable in most codecs. A codec is a program that is capable of encoding or decoding a digital data stream. No visual difference can be seen when using the full frames compressionless method verses the Microsoft Video 1 method.

After all of these options are set the video is exported using the Microsoft Video 1 method. On a Dell Precision M2800 machine with eight gigabytes of RAM it takes about 10 minutes to record 23 seconds of video. After the videos were recorded they were saved in the *Videos* file and were ready for review.

5.5 Unsuccessful Methods

A number of unsuccessful methods were attempted before the successful methods were implemented. This section discusses the failed attempts and why they failed.

5.5.1 Google Earth Pro

Google Earth was unable to import the JPEG files that were used throughout this project. It was able to import GeoTIFF files but using GeoTIFF files would require extra conversion steps to be implemented in this project. Google Earth was also unable to display these raster datasets at full resolution. Using high resolution raster datasets also significantly slows down the software's performance.

Another reason Esri ArcGlobe was chosen over Google Earth was because using ArcGlobe offers cross platform compatibility. Raster datasets could be manipulated in ArcMap, stored in geodatabases, organized in ArcCatalog, and displayed in ArcGlobe. Using Google Earth required extra steps.

5.5.2 Other Esri 3D Platforms

Esri ArcScene was initially selected as the platform to complete this project. However it became clear that Arc Scene is not designed for this type of data visualization. ArcScene is unable to display raster images at full resolution. When a raster image is loaded into ArcScene it resamples the image at a lower quality. If these settings are changed by changing quality, changing resampling method, or changing the number of pixels displayed in a raster dataset, the application crashes.

ArcScene is intended to be used for 3D analysis, not display. It is unable to display county-sized elevation datasets or image datasets. It is mainly intended for use on local level datasets. ArcGlobe is intended for display and presentation. This allows ArcGlobe to use large high resolution image files and large elevation datasets.

ArcGIS Pro 1.0 can display large 3D scenes with a high level of detail. However, it currently cannot record fly-throughs. This capability was essential to the completion of this project. This feature may be added in future versions of ArcGIS Pro.

5.5.3 Video Recording Methods

ArcGlobe provides the option of creating an animation track from the fly-by-bird feature. This feature allows a user to freely navigate by moving their mouse. Each right click of the mouse causes the camera to move faster while each left click causes the camera to slow down or move backwards. However, creating an animation track using this method is not recommended. This feature is very difficult to control and can lead to undesired movements in videos. This is why converting bookmarks into key frames was implemented instead. This method provided precise control verses the shaky frustrating control of the bird.

Another method for exporting videos is the Full Frames Uncompressed method. This method is recommended for recording the very highest quality videos, but was not used because the videos created from this method could not play on standard codecs. There was no visible difference in video quality from Microsoft Video 1, so Microsoft Video 1 was chosen instead.

5.6 Summary

The first step in implementing this project was creating the scene. Images needed to be georeferenced properly to coincide with other data and be displayed in 3D. After the image data were georeferenced, elevation data could be applied to the raster datasets. The raster datasets could then be cached to facilitate fast high quality navigation and animation tracks. Unique vector symbology was applied to provide context for some of the scenes and to symbolize the White House Ruins feature that could not otherwise be symbolized with orthographic imagery. The Shavano Valley Petroglyph was georeferenced to be displayed for its aesthetic appeal in 3D. Animation tracks were then created and exported to video in order to display the 3D features on the stage.

Chapter 6 – Results

This chapter showcases the final products of the 3D Cartography for a Theater Production project. This includes representing each video by sequential images. Each figure in Chapter 6 highlights a different video used in this project. All of the animation tacks were exported to AVI video format through the process described in section 5.4. This chapter also discusses viewer reactions. A summarized quotation was taken from the client and feedback was received from viewers at the 2015 Esri User conference.

6.1 Videos by Keyframe

Each figure represents a video and the intermittent keyframes that were used to construct their animation tracts.

6.1.1 Canyon De Chelly Geovisualization

The Canyon De Chelly visualization starts at the visitor's center to the west of the park. The camera first moves along the road that accesses the canyon but then flies through the middle of the canyon. The camera stops at the access parking-lot for the White House Ruins, and then travels backwards to explore other parts of the canyon while flying between the canyon walls. The camera then moves to a dramatic cliff that juts into the canyon. The camera ends inside the canyon with a perspective view from the ground. The video is 90 seconds long and utilizes Digital Globe imagery data.

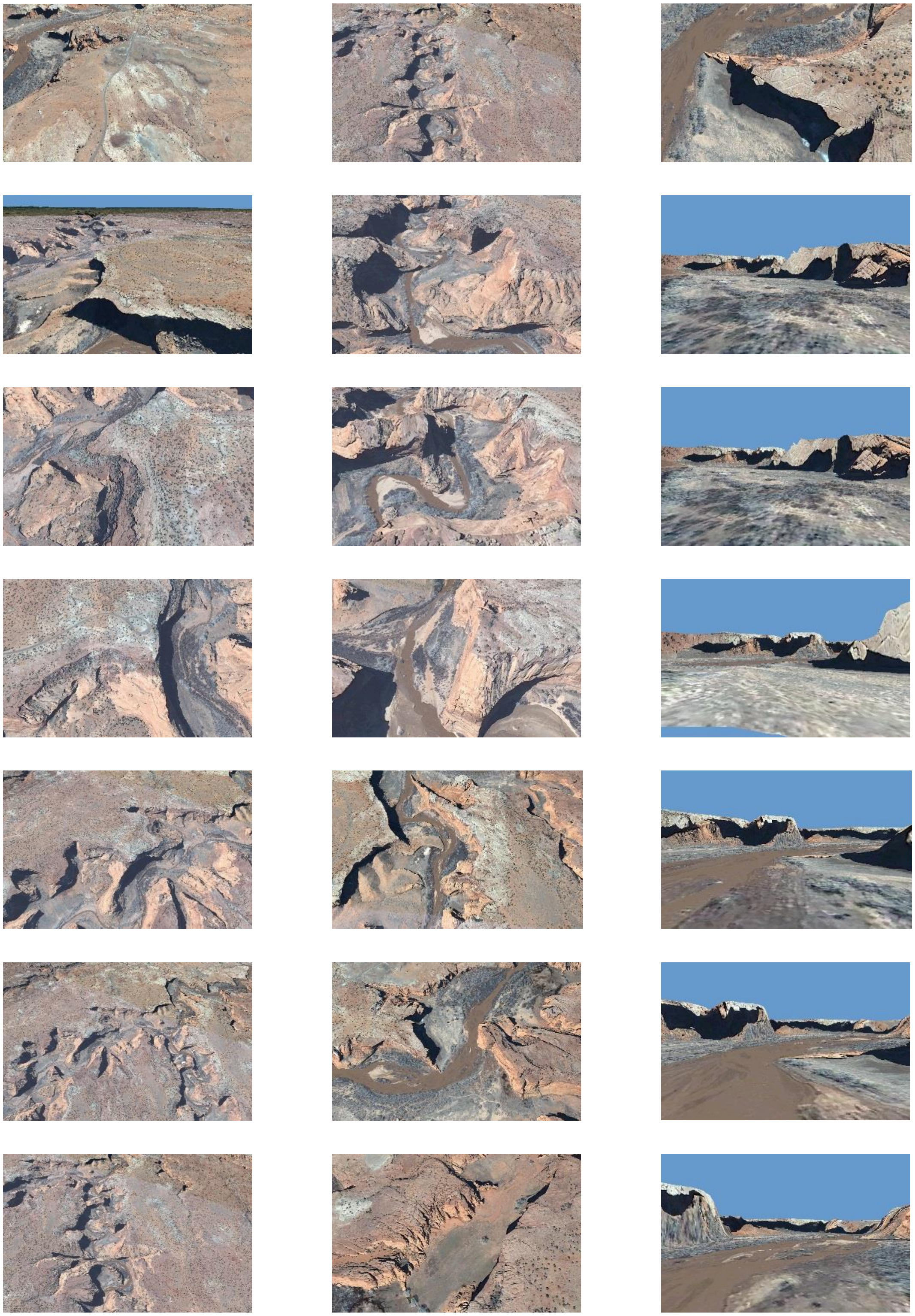


Figure 6-1: Sequential images from the Canyon De Chelly video

6.1.2 San Francisco Mountains Geovisualization

The San Francisco Mountains visualization utilized a historic USGS topographic map as referenced in Section 4.3. The camera follows a track based on geographic features described in chapter 1 of the book *Where the Rain Children Sleep* (Engelhard, 2004). The camera moves from Sunset Crater in the east to Humphrey's Peak in the west, and then to O'Leary Peak in the east. It finishes by panning out to a view of the entire map. This visualization highlights the 3D label symbology that was described in Section 5.2.

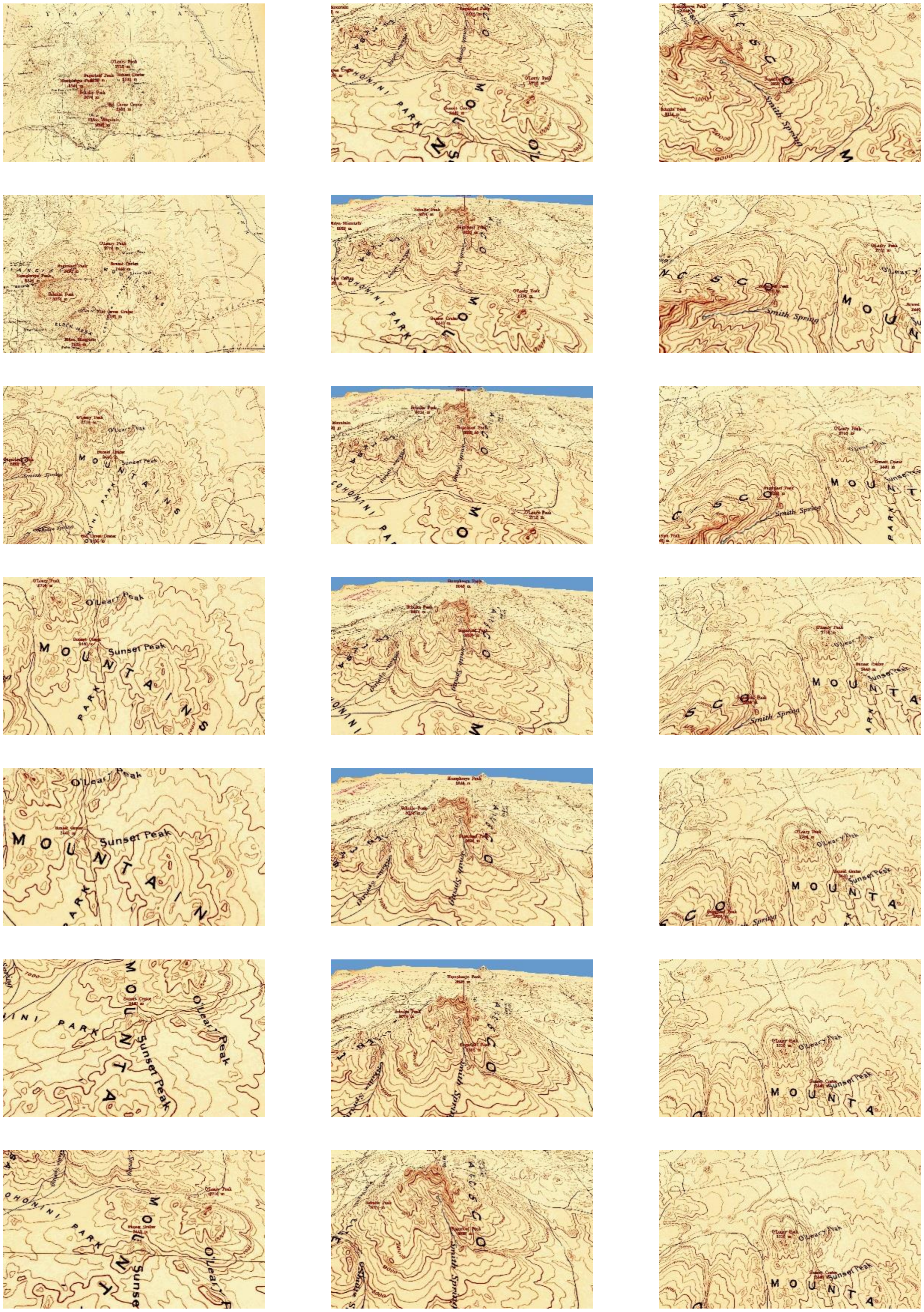


Figure 6-2: Sequential images from the San Francisco Mountains video

6.1.3 Sunset Crater Trail Geovisualization

The Sunset Crater Trail visualization follows a path to the Sunset Crater. The camera starts in a small town with a view of the Sunset Crater. The camera then follows a trail in to the surrounding forest and across a plateau to the foot of the Sunset Crater. The camera then rises along the curve of the volcano and ends with a view of Humphry's peak on the horizon. This visualization was meant to follow a trail a character in the play may travel during the performance.

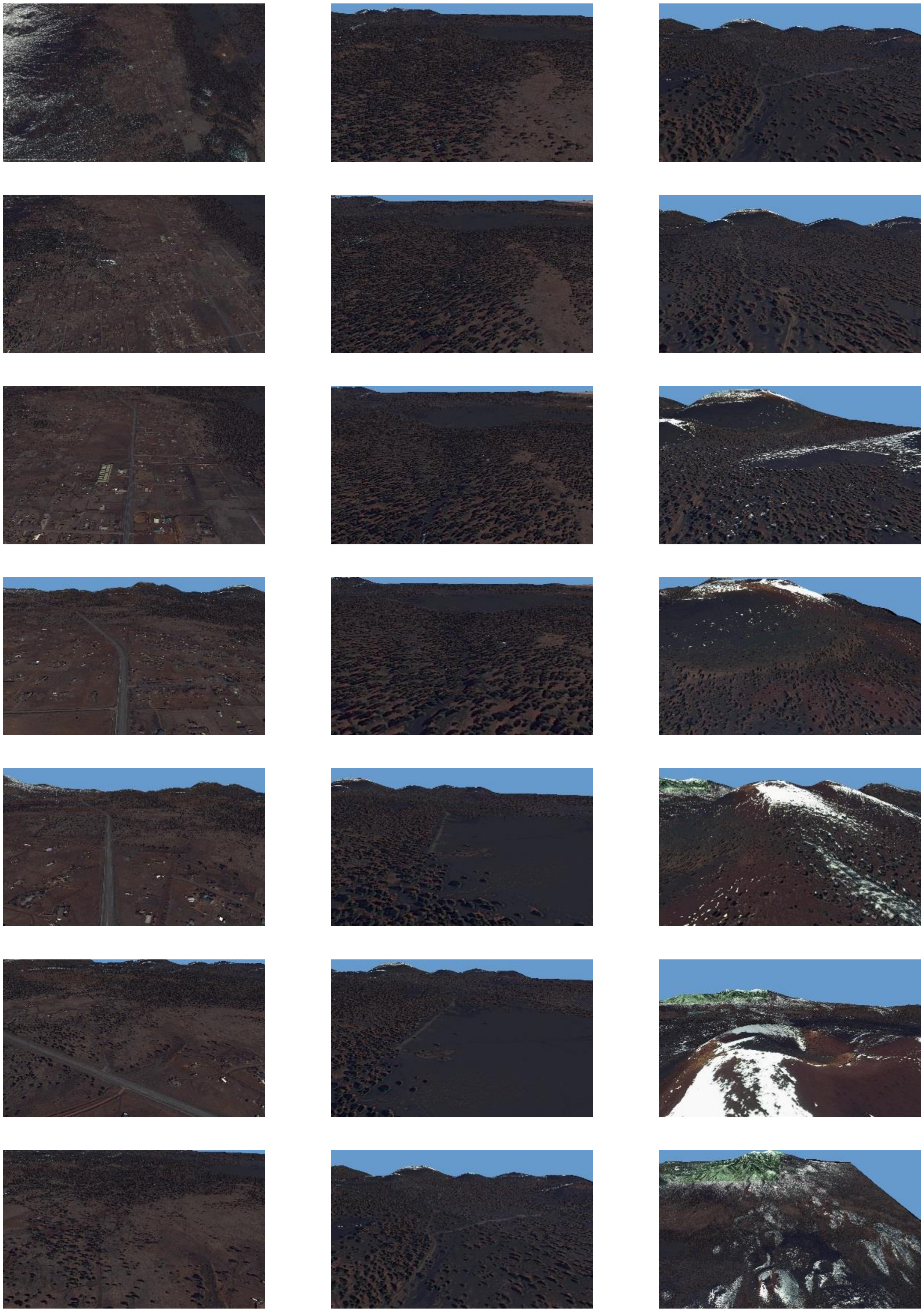


Figure 6-3: Sequential images from the Sunset Crater Trail video

6.1.4 Shavano Valley Petroglyph Geovisualization

The Shavano Valley Petroglyph visualization depicts the petroglyph that was georeferenced and displayed in 3D through the process described in Section 5.3. This visualization is meant to showcase the petroglyph and its ability to coincide with the land scape it is believed to represent as described in section 2.4. The camera simply pans around the scene zooming into different areas to display features in greater detail. A transparency of 35 percent was applied to the petroglyph so viewers are able to view the landscape underneath.

Figure 6-4: Sequential images from the Shavano Valley petroglyph video

6.2 Client and Viewer Feedback

The project's client, Professor Chris Beach, was very enthusiastic about having a GIS expert create visualizations for his project. He explained that the work on this project helped fend off any doubts about GIS playing a role in the visual design of a theater production. He stated that the 3D visualizations could help play a major role in helping the stakeholders present and read through the play. The 3D visualizations provided inspiration for writing characters. He wrote that GIS implementation provided a good framework for learning about the central character's motivations and methods during the plot. He also said that this project's input has also been helpful in the formulation of the unique design of a Geodesic theatre space well suited to the projection design concept for the show (Beach, personal communication, July 26, 2015).

The San Francisco Mountain, Shavano Valley, and Canyon De Chelly videos were all displayed at the 2015 Esri User Conference as a part of a presentation in the *Designing the New Map* cartography paper session. At the conclusion of the presentation the visualizations were met with praise and compliments. One attendee stated that the idea to georeference a petroglyph was very creative. Another attendee stated that the visualizations were very enjoyable to watch. It is fair to say that the visualizations were well received by the audience of GIS professionals.

Chapter 7 – Conclusions and Future Work

The result of the 3D Cartography for a Theater Production project was a set of geovisualizations made in the ArcGlobe module of ArcGIS 10.2.2. They were exported to an AVI video format that could be easily implemented on a stage via a video projector. The geovisualizations are of different sites that are significant to the plot of the theater production. They include trails that were walked by characters in the play or trails that were mentioned in the book *Where the Rain Children Sleep* (Engelhard 2004). The geovisualizations were made from raster data such as DEMs, topographic maps, National Park Service visitor maps, and an image of a petroglyph. The raster data were then projected into 3D and exported as video geovisualizations. The geovisualizations were meant to be projected on stage and interacted with by actors in the production. These videos were delivered to the client before the first rehearsal. The videos were praised by an audience of GIS professionals at the Esri User Conference, and the client found them useful to his project. Instructional documents on how to recreate the project were also written so that GIS users at the University of Redlands Center for Spatial Studies are able to recreate the project and produce additional geovisualizations. It was not possible to test projection mapping software and hardware because it was not available at the time of this project's implementation.

The videos produced for this project were only about 30 seconds in length In the future it may be desired to create videos that are several minutes long. The software certainly allows for this extended length but it would take much longer to record these extended videos. The process for creating these videos could be applied to many different projects that require data to be displayed in a dynamic and engaging way.

There are currently no official cartographic standards or conventions that professional 3D maps must adhere to. As 3D maps become more prevalent a cartographic standard may be developed and the 3D visualizations could be revised to meet the new standard.

As ArcGIS Pro continues to advance it may be more efficient to produce geovisualizations entirely on that platform. Currently it has no video exporting capabilities but this may be remedied in the future. The use of GeoPDF files would have also been very useful to this project; it would have made the process of creating scenes faster and more efficient. There would have been no need to convert files from PDF format to JPEG format. The use of the TerraGo extension would have allowed for the implementation of GeoPDF documents from the USGS website alongside other data in ArcGIS. However this software was unavailable during this project's implementation. Future work in creating 3D geovisualizations could benefit from using the TerraGo extension, especially if files are pulled from the USGS website.

The instructional document provided to the University of Redlands Center for spatial studies served its purpose in providing a workflow so users can easily reproduce certain aspects of the project. If Professor Beach requires additional videos or if another faculty member on the University of Redlands campus requires 3D visualizations, they will be directed to the Center for Spatial Studies where GIS staff will be able to assist them with their project.

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Appendix A. Geovisualization Instructional Document

Creating the Scene

A. Downloading data from the USGS National Map Viewer

- Select and download data from **map viewer** http://viewer.nationalmap.gov/viewer/
- Zoom to the required study area
- Click the "Download Data" button at the top left of the screen
- Select "Click Here to draw and download by bounding box". Draw a box on your map around the study area.
- Check "Elevation DEM Products" This will provide the elevation data set that you will drape the other data upon. Check any other data you require for your study, such as orthographic images or hydrography click "Next"
- In this panel you will select which data you would like to use in your project. This will depend on what your project needs are. (If you click inside the info box without clicking the graphic that is inside it you can see the footprint of the dataset before you download it.)
- Click "Next"
- Click on "Checkout"
- Enter your email and click "Place Order"
- From your email, download your data order. Save to a folder you have designated to use for this project. (Downloading could take 10 minutes or more depending on amount of data you selected.)
- When done downloading, unzip the files.
- Create a folder connection to the unzipped file within ArcCatalog.

B. Customizing the scene

- Load a digital elevation model into ArcGlobe. A dialogue box will appear asking if you would like to use the DEM as an elevation source or an image source. Check "Use this layer as elevation source"
- Click "Finish"
- Load a georeferenced raster dataset into digital globe. It may ask you if you would like to draw pyramids. Click yes to draw the pyramids.
- Zoom to the location of the raster dataset
- To set the elevation source for the raster dataset right click the raster dataset and select "Properties"
- Go to the elevation tab and check "Floating on custom surface" select the DEM as the custom surface. This allows you to use elevation from your own selected DEM.
- To cache the raster dataset right click the raster in the table of contents and select "Generate Data Cache…" select the appropriate extent of the cache. Depending

on the size of the raster dataset it could take several minutes to generate the cache. The cache will allow data to display faster at high resolution, this is necessary

- To set vertical exaggeration right click "Globe Layers" in the table of contents and go to the "General" tab
- Select the desired vertical exaggeration for both "Of Globe Surface" and "Of Floating Layers" Vertical exaggeration highlights subtle changes in the globe surface the higher the exaggeration the more dramatic the changes.

Creating the Video

A. Practice navigating the 3D scene. Navigation in ArcGlobe takes time to get used to but it becomes second nature after practice.

Action	Description
Left Click (Hold and Drag)	Pivots around the scene
Right Click (Hold and Drag)	Zooms in and out from the center of view
Both Mouse Buttons (Hold and Drag)	Pans the view, Similar to Pan in ArcMap

Alternatively you can select the tools from the standard toolbar.

B. Set bookmarks of areas you wish to visit during the animation track.

- Once you are comfortable with a frame you want to visit. Select the "Bookmark" tab at the top of the screen. This will create a spatial book mark that you can revisit at any time. Bookmarks can be saved loaded and managed from the "Bookmark Manager" under the bookmark tab. (It is recommended you name them with a sequential order because you will convert these to keyframes later.)
- Once you have selected a sufficient amount of bookmarks for the animation track you want to create you can then convert these bookmarks into key frames that will be used in the animation track.

C. Convert bookmarks to keyframes:

- To convert bookmarks to keyframes in an animation track open the animation toolbar (Customize, Animation)
- Under the "Animation" tab scroll down to Create "Keyframe…"
- Make sure the "Type" is set to "Globe Camera" and the "Import from bookmark" box is checked
- Click "New" and a new Destination Track should appear in the Destination Track box. You can rename this Destination track if you wish.
- A keyframe name also appears in the "Keyframe name" box. You can rename this keyframe if you would like.
- You can now select the book mark you would like to change into a key frame and click "Create." The first Keyframe in the animation track is created
- In the "Keyframe name" box a new keyframe name is displayed indicating that the next keyframe is ready to be created. Select the bookmark you would like to use and click "Create" again.
- Continue with this process until all desired bookmarks are converted into keyframes.

- After all desired keyframes are created it is time to play the track.

D. Play animation track and set play options:

- Open the "Animation Controls" tool (all the way at the end of the animation track)
- Press the play button to view your animation track.
- To set the length of time click "Options<<" on the "Animation Controls" tool. You can click the "By duration" dial and manually set the amount of time the animation will play.
- You can click the "By number of frames" dial to manually set the number of frames. More frames will result in a smoother video. Other play options can be customized in this menu.
- Test different options for playing your animation track and once you are satisfied you can export your animation to a video file.

E. Export Animation to Video:

- To export an animation to a video file scroll down on the "Animation" tab and click "Export Animation…"
- A dialogue box opens up allowing you to select where the output file will be stored. Make sure the file is saved as an .avi file.
- Once the output file is specified the "Video Compression" dialogue box opens up. Select "Microsoft Video 1"
- Make sure the compression quality is set to 100
- Click configure to set the "Temporal Quality Ratio". Set this to 1. (The Temporal Quality Ratio will affect how jittery the video is, with it set to maximum the video will be smoother.)
- Click "Ok." A video will now be exported from an animation track. The animation track will run as the video is recorded. This could take several minutes depending on how long the animation track is.