VISITORS' GEOLOGICAL CONCEPTIONS AND MEANING MAKING AT PETRIFIED FOREST NATIONAL PARK

Abstract

When observing the natural landscape at National Parks, how do visitors make meaning of the geology? Interpretative geologic displays and programs here are typically uninformed by knowledge of visitor conceptions. Visitors' ideas about geological processes and landscape formation at Petrified Forest National Park in Arizona were investigated by interviewing 80 visitor groups (N= 235) at a landscape overlook and analyzing the results using Verbal Analysis methodology. Visitors were asked to explain landscape formation, depositional environments, and regional uplift of the Colorado Plateau. In the absence of normative geological knowledge about the landscape, visitors frequently used *familiar-place knowledge*: a connection to a particular place with which the visitor has had experience. Qualitative data analysis indicates that visitors: (1) relate landscapes to familiar places, (2) build on religious explanations, (3) superimpose past landscapes on modern ones, (4) patch together bits of information from media sources, and (5) have problems visualizing climatic change. Drawing on these findings, specific recommendations for design and implementation of new interpretative geological displays and programs are presented.

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"One has to be a visionary to speculate about what geologic time has done."
(Petrified Forest National Park visitor from California, 2006)

When visitors to our National Parks look out at the natural landscape, how much do they understand about the geology they are seeing? Alternative conceptions about geological processes abound in the minds of both elementary and college-level students in formal educational settings (e.g., Delaughter, S.Stein & C.A.Stein, 1998; Libarkin, 2005; Lee, Lester, Ma, Lambert, & Jean-Baptiste, 2007), but researchers rarely examine the geological conceptual understanding of adults in informal educational settings such as National Parks. National Parks in the United States draw millions of visitors each year, yet geology interpretive displays tend to be sparse and limited in scope. The National Park Service (NPS) has expressed a desire to develop geoscience education in the National Parks (NPS, 2003), so this work investigates visitors' ideas about geological processes and how visitors then use those ideas to construct knowledge about how the landscape of a particular place, in this case Petrified Forest National Park, is formed.

Petrified Forest National Park (PEFO: the official National Park Service acronym), located on the Colorado Plateau in northeastern Arizona, is ideally suited to this geoscience education research project because of its unique strata, landforms, and fossil resources. These resources constitute highly visible evidence of surface processes and climate change to the trained geologist, but how does the average visitor interpret them? National Park visitors often incorporate visits to more than one park in a region into their vacation plans (Cothran, 2004), so

a coordinated effort to address different geologic processes in each National Park in Arizona is desirable. At Sunset Crater Volcano National Monument near Flagstaff, Arizona interactive displays interlace volcanology with the history and culture of the region (NPS, 2004). Similarly, at the Grand Canyon National Park in northwestern Arizona, Yavapai Observation Station has been rededicated to geology interpretation and "The Trail of Time", a scaled walking timeline trail that models the extent of geologic time, is currently being installed along the south rim of the canyon (Semken, Bueno Watts, Ault, Dodick, Alvarado, & Pineda, 2007).

Geoscience education research is less developed than research in other scientific fields, such as physics, chemistry, and biology. As such, most research efforts remain focused on the formal education realm where research is tightly controlled and subjects are readily found in K-16 classrooms. The informal, or free choice, geoscience education realm, on the other hand, remains relatively unresearched. Most available literature on free-choice education research comes from work done in museums, zoos and science centers (e.g. Rennie, Feher, Dierking, & Falk, 2003; Tofield, Coll, Vyle, & Bolstad, 2003; Falk & Adelman, 2003), with some place-based research being conducted in natural park settings (e.g., Brandenburg & Carroll, 1995; Young, 1999; Stedman, 2003), but very little research has focused on geoscience concepts and how they are perceived and/or understood by adult visitors.

Background

Making Meaning of a Place

"A knowledge of place is grounded in those aspects of the environment which we appreciate through the senses…color, texture, slope, quality of light, the feel of the wind, the sounds and scents carried by that wind" (Ryden, 1993, p. 326).

Perception refers to the interpretation of what we take in through our senses, while meaning is the interpretation the perceiving organism gives to this stimulus information at the psychological level of the individual organism (Williams & Patterson, 1999). This meaning is derived from perceiving what the environment affords, which could be interpreted at a functional level, such as the affordance of food or shelter (Gibson, 1979), or a symbolic level, giving rise to ideas of home or identity (Giddens, 1991). Meanings, therefore, are constructed through experience and common meanings are based on shared or similar experiences between groups of people (Ryden, 1993). In this way, the same place may have multiple meanings for different groups, depending on their interaction with that particular landscape (Greider & Garkovich, 1994). A *place*, then, is a locality given meaning by human experiences (Tuan, 1977).

Place-based Education

The discipline of place-based education stems from the idea that we can leverage the meanings and attachments that people feel for particular places and use them to assist in the construction of new knowledge. Place-based education can be seen as a type of situated learning: a function of the sociocultural or environmental context in which learning occurs. Thus knowledge and skills are most effectively taught in settings and through activities that authentically involve or engage such knowledge and skills (Lave & Wenger, 1991).

Place-based instruction includes describing the physical attributes of a place as well as the cultural, historic, and socioeconomic meanings attached to it. The essential characteristics of place-based education include (a) content that focuses explicitly on the geological and other natural attributes of a place, (b) synthesis, or at least acknowledgement of, the diverse meanings that the place holds for the community and its visitors, (c) instruction by authentic experiences in that place, and (d) support for ecologically and culturally sustainable living in that place (Semken, 2005). The National Park Service and its staff, in the role of stewards of our National Parks, have already embraced the tenets of place-based educational theory (NPS, 2004), and research in individual parks with visitors can be used to inform place-specific interpretation.

Conceptions and the Construction of Knowledge

Conception is the act of creating something in the mind, while alternative conceptions refer to ideas on scientific subjects that are not the same as those accepted by most scientists in a given field. The theoretical framework for this work begins with Piaget-inspired ideas of constructivism, in which the learner builds knowledge using internal cognitive processes acting on stimuli from the external environment. In his "knowledge in pieces" theory, di Sessa (1983) explains that people use intuitive physics elements in the form of *p-prims*, primitive explanations for natural events, to construct knowledge about physics. The same phenomena appears to be happening here as visitors construct knowledge from pieces of information gathered from various sources and cognitively assemble it to create their own unique conception, or alternative conception, of the geological history of formation of Petrified Forest National Park. This work shows that when non-geologists visit our National Parks, they combine their perceptions of the landscape before them with conceptions based on prior knowledge of familiar places in their own experiences and available interpretive information to construct new place-specific meanings.

The Geology of Blue Mesa

Petrified Forest National Park (PEFO) is located on the Colorado Plateau near the city of Holbrook, in northeastern Arizona. Established as a National Park in 1962, Petrified Forest National Park encompasses 93,533 acres and hosts over 570,000 visitors each year. The main attractions to the park are the colorful badland landscapes of the Chinle Formation and the equally vibrant petrified logs that pepper the ground.

Stratigraphy and Depositional Environment

The geological history of PEFO starts over 200 million years ago during the Triassic Period when a large braided river system similar to today's Brahmaputra River -- which runs from Tibet through Bangladesh to the Bay of Bengal -- cut a series of *paleovalleys*, ancient river valleys, into the underlying rock. Erodable banks, rapid and frequent variations in the amount of water present in the river, and large amounts of sediment in the water are all characteristics of braided river systems. The ancient river that coursed through PEFO had its *headwaters*, place where the river begins, in since-eroded highlands to the south and east (Stewart, Poole, & Wilson, 1972), and then ran north northwestward to Monument Valley (Blakey & Gubitosa, 1983).

As this river changed in its course, it left behind a *conglomerate*, rock made of smaller rocks cemented together, composed of clean, round, well sorted and coarse-grained quartz sandstone in addition to finer sediments. *Paleosols*, ancient soils, which range in color from red to reddish-purple and purple, formed adjacent to the river, usually on the floodplains and areas between

stream braids. River marshes also were present in this environment along the edge of the river as were *crevasse splays* – areas where the active channel broke through its banks into an inactive, low-lying region or swamp, depositing fine-grained sediment (Blakey & Gubitosa, 1983).

The landscapes visible in PEFO are primarily composed of sedimentary rock layers of the Chinle Formation. The Chinle Formation is divided into four members 1) Blue Mesa (oldest), 2) Sonsela, 3) Petrified Forest, and 4) Owl Rock. The Blue Mesa Member, approximately 234 million years old, is primarily composed of purple, blue, gray, and red mudstone, and is interpreted as representing paleosol development on floodplains. Volcanic ash weathered to bentonite clay in these layers, and also provided a source of silica for tree petrification. Colors in the rock are due to both the presence and absence of various minerals and the level of the water table at the time of soil formation. Red and green layers usually indicate similar amounts of iron and manganese in the soil. Greenish and bluish soils are formed in a reducing environment when the water table is high and little oxygen is present, while reddish soils are formed when the water table is low and soils are exposed to oxygen in the air, much as an iron nail will rust and turn red when exposed to air and water. About 30% of the Blue Mesa Member is sandstone, including the Newspaper Rock Bed. Visitors are asked to describe the depositional environment of the visible layers of Blue Mesa Member mudstones in this study.

The Sonsela Member of the Petrified Forest Formation formed approximately 227 million years ago and is home to the park's famous brightly colored logs. The Sonsela Member is divided into three parts 1) Rainbow Forest beds (representing events that happened first in time), 2) Jim Camp Wash beds, and 3) Flattops 1 beds. The Rainbow Forest bed is composed of white sandstone with clasts of rounded pebble to cobble-sized chert and quartzite and ripped up pieces of the underlying Blue Mesa sandstone, which are found even up to boulder size and provide evidence that the river had periods during which water flowed through the area forcefully (Heckert & Lucas, 1996). In the study area, the Rainbow Forest bed can be clearly seen near the visitor pull-out with logs embedded in it. The middle Jim Camp Wash beds are blue, grey and purple mudstones, and the Flattops One bed is a brown sandstone which forms cliffs, and can be seen from the study area on the distant mesas serving as a *capstone*, a layer of harder-to-erode rock which protects softer layers underneath it from erosion.

In addition to those layers observable from the study area, the Petrified Forest Member at the northern end of the park frames the panoramic vistas for which the Painted Desert is famous. It consists of sandstones and mudstones in tones of lavender to brown to white containing carbonate nodules, trace fossils, and abundant vertebrate and invertebrate fossils. The 214 million year old Petrified Forest Member also represents deposition in a river environment; however, the 205 million year old Owl Rock Member, present only at the very northern border of the park and not visible from the study area, consists of fine-grained sandstone and fresh water limestone, and was deposited in a lake environment.

The Trees

Two sections of stratigraphy are the main hosts of petrified wood in the park, the Rainbow Forest bed of the Sonsela Member and the Black Forest bed of the Petrified Forest Member. Most of the wood is found in the Sonsela Member. These large, highly colorful, spectacular logs are on display in the south end of the park and can also be found in many areas of private land

surrounding the park. These trees are *Araucarioxylon arizonicum* (Daugherty, 1941) and are akin to modern-day conifers. Visitors observed these trees from the study area.

The *Araucarioxylon arizonicum* found in the Rainbow Forest bed of the Sonsela Member includes specimens up to 60 meters long and 3.5 meters in diameter. Most of the wood found in the park is in the form of logs, which are prone upon the ground. Trees occur in river channel deposits, lack limbs and bark, have roots broken off close to the ground, and generally lie in a preferred orientation between N30°E and N30°W, indicating river transport. Nearby amphibian and reptile fossils suggest this area was swampy at the time of the tree growth (Ash & Creber, 1992). The presence of Alfisols, soils developed under temperate forests of the humid mid-latitudes, also suggest that the area supported open forests during the time of Lower Chinle deposition (Retallack, 1997).

Evidence suggests that the trees petrified in the Blue Mesa area of PEFO were transported by the river that coursed through the area. The logs became entangled in a log jam, sank, and were buried by sediment, which protected them from decay and locked them into the sandstone layers we find them in today. Silica and other minerals such as iron and manganese, derived from volcanic ash, first filled the spaces between cell walls in the wood, and then later replaced the wood itself in some specimens in a process called *petrification*.

Triassic flora and fauna

In addition to the trees, other plant and animal fossils have been uncovered at PEFO. Among the animal fossils are those of large amphibian metopasaurs and archosaurs, crocodile-like reptilian phytosaurs and aetosaurs, dicynodonts, shark teeth, lobe-finned fish spines, non-marine mollusks, clam-shrimp, and insects, including prehistoric bees. Plant fossils include conifers (e.g. spruce), ferns, cycads (e.g. Sago palm), horsetails, and lycopods (e.g. club moss).

Colorado Plateau Uplift

PEFO is situated on the Colorado Plateau, a large, flat area that encompasses approximately 140,000 square miles in the four corners region of Arizona, New Mexico, Colorado, and Utah. 60 million years ago this area began to become uplifted, in some places as much as 10,000 feet above sea level, without becoming deformed. Geologists are not certain what caused this uplift, and it is a subject of continuing investigation today. As the plateau moved upward during this time frame, erosional processes also worked to strip away the layers which had formed on top of the Chinle Formation, exposing the landscape we see today. Although glaciers are not known to have existed in PEFO, wind and water both continue to play their parts as erosional forces here.

Research Methods and Data Analysis

Data Collection Methods

The researcher conducted structured interviews of 80 groups of visitors at PEFO during a one-week period in July 2006 (n = 50) and another in December 2006 (n = 30). These interviews were consistently conducted at a point about halfway through the park, the first visitor pullout of the Blue Mesa Loop at PEFO, a location selected because petrified trees are clearly visible in-situ within well-defined, visible, layers of the Chinle Group here. Since the researcher is

interested in how visitors use their perceptions of the natural landscape to interpret geology, it was necessary to use the landscape as a prompt.

Data were collected from a wide variety of visitors, who were generally approached after they had exited their car and walked a short distance from it. The researcher introduced herself as a graduate student from Arizona State University working on her Master's project, requested participation from the visitor group, and asked for verbal consent to audio record. Using this technique, over half the visitor groups approached consented to be interviewed, although the percentage of participants declined rapidly during both lightning storms (summer monsoons) and snowstorms (the researcher was snowed in for two days during the winter – hence the lower number of participant groups during that season).

Visitor participants were asked five scripted questions: 1) How do you think the landscape you see before you came to look the way it does today?, 2) What do you think this area looked like during the time the layers you see in these mesas were formed?, 3) How do you think the trees you see before you got here?, 4) What do you think this area looked like during the time these trees grew?, 5) Petrified Forest National Park is located on the Colorado Plateau, which is a large flat area that encompasses approximately 140,000 square miles in the four corners region of Arizona, New Mexico, Colorado, and Utah. Parts of the Colorado Plateau have been lifted as much as 10,000 ft. above sea level. How do you think that happened?

The first author transcribed and reviewed all the interviews of the day nightly. In addition to interviews, she collected print and film materials available to visitors both on-site and through the PEFO web site, and attended selected interpretive programs to discover what interpretive information is readily available to park visitors. She also examined the geology research materials available to park staff and researchers in the PEFO staff library and participated in informal conversations with park interpretive staff and scientists to gain perspective from a park staff point-of-view.

Verbal Analysis Method

Qualitative methods are normally used in situations where research is being conducted in a natural setting. Data analysis followed the Verbal Analysis methodology of Chi (1997), a method of quantifying qualitative data. The stated goal of the verbal analysis method, according to Chi (1997), is "to attempt to figure out what a learner knows (on the basis of what a learner says…) and how that knowledge influences the way the learner reasons and solves problems, whether correctly or incorrectly" (p. 273). Verbal analysis technique outlines a way to both quantify what is said and dig deeper underneath what is said to establish relationships in thinking behind the words. The combination of these two pieces of information leads to a way to design instruction to add to the subject's knowledge, in this case that of the National Park visitor seeking to learn about the geology of PEFO.

In verbal analysis the categories for coding emerge from the data, unlike other methods of qualitative data analysis, such as protocol analysis (Ericsson & Simon, 1984), in which the data coding categories are set a-priori. This allows for a fuller variation in understanding to be expressed and evaluated, especially when the data are particularly broad in source and scope, as

was the case in this project. In the verbal analysis method, qualitative data are used to generate categories that are then coded, counted, and analyzed quantitatively as well as qualitatively.

Data Analysis

After transcribing all the interviews and reading through the corpus several times, the researcher reduced the protocols by analyzing only the summer group (n = 50) first, reserving the winter group (n = 30) for hypothesis testing. Since each interview consisted of five standard questions, each question was coded separately as a segment. The grain size used was that of an idea, with some ideas being expressed as a single word. Categories emerged from data, with new categories being added as ideas did not fit existing ones. The researcher expanded data to as many categories as needed at first, and then contracted those categories by combining like ideas together. For example, categories of deposition, rock, sand, silt, mud, sediment, clay, evaporates, minerals, chemicals, salts, ash, tephra, and layers existed separately at first, then were collapsed down to be sub-categories under "deposition", which in turn joined erosion, transportation, weathering and evaporation to form a "gradation" category (see Table 1).

After the summer data were coded and categorized, two undergraduate research assistants – one geology major and one psychology major – coded the winter interviews using categories based on the summer data. Throughout this process, any questions concerning coding were first discussed between the assistants, and then brought to the attention of the researcher. During this time the primary researcher consolidated the categories from each of the five questions into one extensive list, integrating categories within the segments. The research assistants then re-coded the summer and winter data separately using the new consolidated category list. Finally, the tallies from both the summer and winter data sets were combined to produce total numbers of instances of ideas for each question.

Data were also analyzed with regards to the number of different ideas each group expressed per interview. In this case the data were revisited again, and each category on the cumulative list was searched for only once within the corpus of the interview. Each category was assigned a value of either 1, signifying that the category had been expressed, or 0, signifying that the category had not been expressed. All 80 interviews were examined for each of the 80 final categories, and totals were calculated for the number of ideas expressed in the summer, winter, and total combined.

Table 1

Categories (in bold) and Subcategories Emerging from the Data

Water – rain, flood, river, ocean, inland sea, lake, and glacier

Wind – *no subcategories*

Erosion – differential erosion and mass wasting (gravity)

Deposition – rock, sand, silt, mud, sediment, clay, minerals, ash and layers

Impacts – *no subcategories*

Volcanism – lava, magma and eruption

Tectonism – plate tectonics, plates, Earth moves, continental movement, earthquakes, faults, mountain building, uplift, mantle processes, force under ground, pressure

Geological Environments – floodplain, delta, mountain, plateau, valley, prairie, ocean bottom, volcano

Ecological Environments – swamp, forest, jungle, lush vegetation, fertile soil, desert, dinosaurs and other creatures

Trees – transported, grew in place, knocked down, petrified, were broken by…, log jam, sank, grew from seeds, buried

Climate – weather, tropical, climate change

Time – over time, at one time, years, centuries, millennia, millions of years, billions of years, geologic time, Cretaceous, Jurassic, Triassic, 40 days, Time of flood

Sources of Knowledge – knowledge of home or familiar places, scientific evidence, observation, park documentary, visitor center, interpretive signs, readings, religious teachings, geology classes, family discussion, TV, movies, other parks and attractions

Results

Demographics

Visitor social units ran the gamut from family groups on vacation (46%), couples (38%), friends (8%), and solitary visitors just passing through (6%), to tour groups (3%), including a 31-person high school student math and science tour group from Ohio, with 235 visitors participating in total. Females (n = 117) and males (n = 118) were represented equally within the visitor groups. Decadally binned visitor age groups show a bimodal distribution, with 11-20 year olds being the largest group (21%), followed by 21-30 year olds and 61-70 year olds (16% each), 31-40 year olds, 41-50 year olds, and 51-60 year olds (12% each), 71-80 year olds (6%) and 0-10 year olds (3%). Age groups varied by season, with visitors under 20 making up 30% of the summer sample, and only 12% of the winter sample. Although the winter sample was collected during the week between December 25th and January 1st and school was not in session, a reduced number of younger visitors is typical for the park during this time frame. PEFO staff had also expected a larger number of retirees during the winter months, but this was not born out by the data, with visitors over 60 comprising 18% of the winter sample as opposed to 24% of the summer sample. A possible source of skew here is the fact that many seniors travel in tour buses during winter, and their time at any given stop like Blue Mesa is very short; the researcher was only able to interview one. The percentage of visitors aged 21 through 50 who visited the park in the winter (64%) was twice as large as that of the summer (32%).

Interview Questions and Answers

Visitor ideas, when coded, fit into 13 main categories: water, wind, erosion, deposition, impact events, volcanism, tectonism, geological environments, ecological environments, trees, climate, time, and sources of knowledge.

How did the landscape come to be the way it is today?

When asked about the formation of the landscape, visitors answered with an average of 5.63 ideas (n = 450) per visitor group. The categories most frequently articulated were deposition at 21% (n = 92), erosion at 17% (n = 75), and water at 19% (n = 85). Wind was only seen as an agent of landscape formation 4% of the time (n = 18). Time was mentioned in 10% of the total ideas (n = 46), while 9% of the ideas (n = 38) volunteered sources of knowledge, six of those equating the landscape to a familiar place. Tectonism (n = 22) and ecological environments (n = 21) each encompassed 5% of the total ideas, while the remaining categories showed 3% or less in total ideas. Most visitors recognized that water plays a part in the landscape formation story at PEFO. Rain and wind were cited as agents of erosion, which most visitor groups conceded as part of the story. Twelve groups talked about differential erosion playing a part in the strange shape of the current landscape, and four groups discussed mass wasting due to gravitational forces emplacing petrified logs in valleys of the present landscape. The category of deposition includes sub-categories of sediment and mud deposition (n = 23) and minerals (n = 26) responsible for the coloration of both petrified trees and the landscape layers, which were referred to 11 times. Visitors also mentioned rocks, primarily sandstone and mudstone, 17 times during the explanations given for this question. What is interesting, however, is that only one visitor mentioned the volcanic ash responsible for the petrification of the wood clearly visible in the landscape. Additionally, the river, which is thought to have covered most of the landscape, was only mentioned five times, while 12 visitors talked about the landscape being formed under an ocean, an interpretation that is not part of the PEFO story. Five visitors also mentioned that

glaciers carved the landscape, which is not supported by scientific evidence in this location, and five visitors cited the biblical Noah's Flood as being directly responsible for the entire landscape.

What did this area look like during the time the layers in the mesas were formed?

When asked what the landscape looked like when the clearly visible layers in the mesa were being formed, visitors answered with an average of 4.125 ideas (n = 330) per visitor group. The categories most frequently articulated were water at 24% (n = 83), deposition at 15% (n = 50), geological environments at 14% (n = 48) and ecological environments at 14% (n = 48). Climate (n = 25) comprised 8% of the total ideas, while time was mentioned in 6% of the total ideas (n = 20) and 6 % of the ideas (n = 20) volunteered sources of knowledge, six of those equating the landscape to a familiar place. Erosion (n = 15) encompassed 5% of the total ideas, while the rest of the categories showed 2% or less in total ideas.

Most visitors recognized that water plays a part in layer formation. Rain and flood (n = 2) were mentioned together, as part of Noah's Flood in biblical times. Many visitors described the area as being an ocean (n = 22) or the area as ocean bottom (n = 12) at the time of deposition. Visitors do not have a clear idea of what the landscape looked like at this time. Five visitors described a floodplain and two a delta, either of which is consistent with current scientific thought, but the area was alternately described as being a mountain (n = 7), a plateau (n = 4), and a valley (n = 3) at the time of formation. In addition, 15 visitor groups described the area as having been a plain or a prairie akin to those found on the Great Plains. Visitors are also unclear as to what the flora and fauna looked like during this time period. The most frequent description given was that of a forest, however the visitors were clearly confused as to whether that forest looked like a typical conifer forest (n = 22) or a rainforest such as those found in the Amazon jungle (n = 7). Another environment suggested was a swamp, akin to those found in Louisiana (n = 11), but visitors had problems trying to visualize how the climate could have changed so drastically (n = 25). Dinosaurs and other creatures (n = 3) were also visualized as having roamed the land at that time.

How did the trees get here?

When asked how the trees came to be where they are today, visitors answered with an average of 4.95 ideas (n = 396) per visitor group. The categories most frequently articulated were trees at 22% (n = 88), deposition at 18% (n = 72), water at 16% (n = 62), and ecological environments at 14% (n = 57). Climate (n = 19) comprised 5% of the total ideas, while time was mentioned in 6% of the total ideas (n = 25) and 8 % of the visitor ideas (n = 31) volunteered sources of knowledge, six of those equating the landscape to a familiar place. The rest of the categories showed 2% or less in total ideas. Most visitors recognized that water plays a part in the story of the petrified trees at PEFO. Three visitors mentioned torrential rain as responsible for the felling of the trees and their transportation downriver. With this question, however, most visitors who mentioned flood (n = 13) related it to the transportation of the trees, only one visitor referenced Noah's flood. This question seemed to bring the idea that a river system existed in this place at one time to the forefront, as 23 visitor groups mentioned the trees being transported or deposited by a river. Oceanic references offered scenarios of logs being deposited into the ocean after transport, or the seas rising up to cover the buried trees for a long period of time. Deposition was recognized as being important to the story of the trees by 29 visitor groups, with sediment (n = 16), and rock (n = 4) also mentioned. Interestingly, although 14 visitors described a petrification

process in which minerals play an important role, only six mentioned the volcanic ash involved in this process.

Confusion exists among visitors as to where the trees came from and how far they traveled before coming to rest at Blue Mesa. Although 29 visitor groups reported that the trees had been transported, nine decided that the trees had grown right where they lay today. Visitors declared that the trees had been either knocked down or fell down (n = 14), were involved in a logjam (n = 3), became heavy with water and sank (n = 4), were buried or covered with sediment (n = 8), and became petrified (n = 12). These ideas are consistent with the scientifically accepted story at PEFO, although some debate exists as to whether or not trees grew near this location. Some visitors mentioned that the trees grew from seeds (n = 6), but within that group three stated the seeds had been carried by wind, two favored transport by birds, and one believed that the trees were planted by humans.

What do you think this area looked like during the time these trees grew?

When asked what the landscape looked like when the trees were actually growing, visitors answered with an average of 3.24 ideas (n = 259) per visitor group. The category most frequently articulated was ecological environments at 45% (n = 117). Climate (n = 35) comprised 14% of the total ideas, with water discussed by 10% of the groups (n = 26). Time was mentioned in 5% of the total ideas (n = 13). Nine percent (n = 24) of the ideas expressed sources of knowledge, with nine of these equating the landscape to a familiar place. Geological environments (n = 18) were talked about by 7% of the visitor groups, erosion (n = 12) encompassed 5% of the total ideas, and each of the remaining categories was represented by 2% or less of the ideas.

Most visitors included a description of a forest (n = 46) in their response to this question, but the type of forest that supported the growth of the trees apparent in the present-day landscape varied within visitor groups. Some visitors described the area as being a tropical rainforest (n = 10), and some included lush vegetation (n = 33).Visitors do not have a clear idea of what the forest looked like at this time. Among the descriptions given by visitors were woodland, pine forest, conifer forest, mixed forest, wet forest, lagunal forest, big forest with big trees, patches of forest, ferns and tall prehistoric grass. Two visitors described the soil as being fertile. Visitor groups visualized the trees growing in a swamp (n = 19), and some added dinosaurs and other creatures (n = 17) to their picture. Among the animals described were birds, reptilian-like animals, fish, dinosaurs, something for the dinosaurs to eat, and dinosaur-sized mosquitoes. The most reported geologic landscapes were a plain, prairie, or flatland (n = 12), while three visitor groups report that the trees grew on mountains, and one visualized a floodplain. Climate or weather was discussed (n = 35), as most visitors realized that the climate must have been wetter and more tropical (n = 9) for trees to have grown to the size indicated by the petrified logs. Eleven visitor groups also mentioned that climate change must have occurred in the area between the time of tree growth and present day, with four groups reporting that the area was near the equator at the time.

How did the Colorado Plateau become uplifted?

When asked how the Colorado Plateau came to be uplifted, visitors answered with 217 ideas in total, an average of 2.71 ideas per visitor group. Many visitor groups replied that they had not thought about this question, and really did not know the answer, but then made an attempt to

reason it out. A large number of visitor groups explained that tectonics came into play, with 139 ideas about tectonism being expressed. Some groups stated more than one aspect of tectonics was important. Ideas of volcanism were mentioned ten times (5%). Ideas in the water category were mentioned 18 times (8%), time 4% (n = 8), and sources of knowledge 8 % (n = 17 : 7 of those equated the landscape to a familiar place). Geological environments (n = 9) were cited by 4% of the visitor groups, and deposition (n = 8) encompassed 4% of the total ideas, while the rest of the categories had 2% or less of the ideas.

Most visitors included the idea of uplift (n = 28) in their response to this question, but the mechanism responsible for that uplift varied within visitor groups. Many visitor groups explicitly stated the idea that plate tectonics was responsible (n = 25), while others discussed the action of plates (n = 21), and some used only the word tectonics in their description (n = 6). If these three sub-categories are added together, however, 53 visitor groups suggested some role for plate tectonics. In addition, visitors also described continental movement (n = 13) and earth movement such as slippage (n = 9). Earthquakes were also described by visitors (n = 13), as were faults (n = 5), and mountain building processes (n = 3). Visitors also discussed mantle processes (n = 3), underground forces (n = 9), internal pressures of the Earth (n = 4), and volcanism (n = 10).

Time

Most visitors realized that time played an important role in the PEFO story, and answered with an average of 1.40 ideas about time (n = 112) per visitor group. The category most frequently articulated (33%; n = 117) was a general statement that the changes occurred over time. Other general statements included the idea that events happened at a specific time or point in time (n = 18), or that events happened a long time ago, during prehistoric times, over geologic timescales, or during dinosaur times (n = 16). Time scales mentioned by visitors ranged from 40 days (n = 2), years (n = 12), centuries (n = 2), millennia (n = 5), millions of years (n = 7) to billions of years (n = 2). The visitors who mentioned the 40-day timescale also referred to the time of Noah's flood, in reference to biblical teachings. Some visitors were able to speak specifically about geologic time, and talked about events that took place 22 to 50 million years ago (n = 4), 200 million years ago (n = 7), or during the specific periods Cretaceous (n = 1), Jurassic (n = 3) or Triassic (n = 5).

Sources of knowledge.

Visitors use diverse sources of knowledge to construct their interpretation of the PEFO story, and referred to or implied these sources an average of 2.75 times per visitor groups (n = 220). The PEFO Visitor's Centers comprised the bulk of instances of these ideas, with 91% of visitors reporting that they had stopped at one of the visitor's centers upon entering the park when questioned (n = 73), although only nine visitors (11%) reported the visitor's center as a source of their response. A documentary movie about PEFO, *Timeless Impressions,* is also popular with visitors, with 44% of visitor groups reporting that they had attended the screening (n = 35). In addition, 34% of visitor groups incorporated prior knowledge of their homes or other familiar places when explaining the geology at PEFO (n = 27). Scientific evidence or direct observations were verbalized by 20% of the visitor groups (n = 16), while 11% of visitors (n = 9) relied on religious teachings or beliefs to make sense of the landscape. Visitor groups referenced or volunteered they had visited other national parks or attractions in the area 29% of the time (n = 23). Visitors also reported reading printed material (n = 9) and interpretive signs (n = 3),

attending geology classes in the past (n = 11), gathering information from television or movies (n = 3), or having family discussions (n = 2).

Interpretations

Visitors use various sources of information when they construct new meaning about the natural landscape. This meaning construction seems most successful with the synergy of a combination of factors. At Petrified Forest National Park, most of the information visitors have gathered to construct meaning from the landscape seems to have come from the park movie. Visitors repeatedly reiterated the story told in this film with differing levels of accuracy throughout the study. In the absence of verbatim recall of the information presented in the film, however, visitors used additional sources of information to answer the researcher's questions. The most powerful of these tools seems to be *familiar-place knowledge*, a connection to a particular place with which the visitor has had experience. In the absence of this familiar place connection, visitors frequently express ideas that are not normative for this location at this time. Often, however, familiar-place knowledge can also lead to misinterpretation of the landscape in the absence of additional interpretive information from which the visitor can draw ideas. In addition, drawing interpretive information from religious teachings seems to lead to both normative and non-normative meaning making as well.

For example, when asked to describe what the area looked like at the time the trees were growing, a visitor from Michigan observed:

> (M65, signifying a 65-year old male) That looks like a mountain of Maine trees that all went to the sawmill and there you have what's left…
> (I) What do you think this area looked like during the time these trees grew?
> (M65) Like an upper peninsula White Pine Forest. Although that's more Hemlock…You go up to Heartwood Pines in Upper Michigan, and they have a White Pine grove, probably like that… (07270607)

In this case the visitor observed small pieces of petrified wood which litter the ground in this area and equated what he saw to the tailings from a sawmill in Maine he had familiar-place knowledge of. He then linked that information to a white pine forest in upper Michigan familiar to him and decided that the area must have looked similar to Heartwood Pines in Upper Michigan. In this case the visitor made an observation, linked it to a familiar place, and used familiar-place knowledge to make an interpretation of the landscape.

In a second example, when asked to interpret what the area looked like at the time the trees were growing, a visitor from the United Kingdom replied:

> (M60) A bit like Jurassic Park. Lots and lots of vegetation. A lush, lush area. But I guess not this actual area, but where the trees have been washed down from is like that. Here it was more like water. (07300640)

In this case the visitor recalled the idea that the geology was formed around the Jurassic, connected that with interpretive information from the movie *Jurassic Park*, described that

environment, recalled that the trees were supposed to have grown in a different area and washed into Blue Mesa, observed the sedimentary layers, and concluded that the area was underwater.

Another occasion of a visitor using familiar-place knowledge to interpret geology is illustrated by the following interview:

> (M 55) Well, like in West Virginia it would be more like a huge farmland with big trees on it in certain areas, and it looks like you have that here. Trees aren't everywhere. We noticed as we were coming in it was kind of spotty, maybe over time people have taken a lot of them, I don't know. So I would just say that some prairies have trees and some don't. It looks like there's a meadow. That might have been a meadow with water flowing down through it. (07270614)

Again, when asked what the area looked like during the time the trees grew, the visitor immediately equates the growth of trees with a familiar place in West Virginia, a farmland with intermittent tree growth. This makes sense to him because he sees that trees are "not everywhere" in the landscape, which fits his mental model, although he does entertain the idea that people may have removed some of the wood. He translates *farmland* into *prairie*, and then adds that some prairies have trees and others do not, building a picture of a flat prairie-like area. Then he imagines a meadow in the
landscape and concludes that the area might have been a meadow with water flowing down through it, which is most likely reflective of his familiar place.
A visitor from Arizona explained how the trees came to be where they are today as follows:

> (M 55) I been in this state for 40 years, and there ain't a whole lot of trees in it. The guy from the Visitor's Center, he said they came from the north in a flood. I supposed that's possible. If you go back and study recorded history, why the Bible says that Daniel fought with lions and bears. You don't find them in the desert, so obviously Israel was not a desert at one time, which it looks more like Arizona now. So there must have been some kind of climatic change. (07280616)

He began with an observation based on experience by commenting that he had lived in Arizona for 40 years and there are not a lot of trees growing in it. With this statement he is conflating events through time by equating the time of tree growth to today. The shortening of time scales can be explained by his next leap in thought. He thinks of Arizona as being desert, and then draws a parallel mental model with modern-day Israel, which is also desert. Biblical teachings – which he refers to as recorded history -- now become a source of interpretive information, and the story of Daniel fighting with lions and bears comes to the forefront. He accesses his familiar-place knowledge and goes on to explain that these animals do not live in the desert, so Israel must not have been a desert at that time. His conclusion then becomes that, since the climate must have changed in Israel, it must also have changed in Arizona, so he now builds a new mental model that allows for the growth of big trees on the Colorado Plateau at some point in the past.

The combinations of pieces of knowledge that visitors use to make meaning of the landscape is, of course, endless, but it seems that visitors are relying heavily on familiar-place knowledge to

construct images of the past landscape. Visitors then mix these visions of a place with other sources of information to render a mental model depicting the formation of the landscape. If their observations do not fit, it appears that they then adjust either the model or their observations to force a fit.

Emergent Themes

Visitors Relate Landscapes to Familiar Places

Several recurrent themes emerged from analysis of the data. The most prevalent of these themes, as discussed in the preceding section, is that visitors relate the landscape they are observing to places from their personal experiences in order to make sense of what they are seeing:

> (M65) The sea bed was under water of some sort. The land was flat. It's very similar to Australia. It's laid out the same way; it's just some different colors because there are different minerals from volcanic action. It's more red in Australia. (07290626)

In this case the visitor observed the landscape, equated it to landscape he was familiar with in his native Australia, uses his familiar-place knowledge of Australia to recall the layers were deposited under water, and so concluded that the layers deposited at PEFO were under water as well. He then observed that the layers at PEFO are a different color than the typical red of the Australian landscape he is familiar with, remembered that the PEFO story included volcanic ash in the wood petrification process, and concluded that the ash was the reason the layers were a different color than the red he was used to.

When asked what the area looked like during the time the trees that are now petrified were growing, one visitor replied in the following way:

> (F50) Well, because I'm from the East, I'm used to trees growing in a moist and green area. But it's always a surprise, when we first came here it surprised all of us…we were surprised to see that you get something like this – rocky gravel and then you see green growing. So, I supposed it could have looked either way…spotty greenery, spotty trees. An Easterner would say lots of green. (07300638)

Although this visitor currently resides in Arizona, she brings her familiar-place knowledge of the eastern United States with her. She recalls that trees usually grow in moist, green areas in her previous environment, and equates the trees in the landscape with the trees she remembers. Then she sees the landscape in front of her, which looks barren like many parts of Arizona, and observes scrub brush and small patches of low-lying plants among the surface gravel layer. She remembers the first time she came to Arizona and was surprised to see that it was not just sandy desert, and concludes that PEFO might have also looked quite barren with only a few trees growing. Then she changes her mind again, but instead of making the statement as if it were her opinion, she uses the point-of-view of an Easterner to frame her final conclusion: "An Easterner would say lots of green."

In this next example, the visitor is asked to speculate about how the uplift of the Colorado Plateau occurred. In the absence of a landscape to observe, the visitor proposes the following:

(F40) Probably streams pushing down. Erosion. The same thing is happening in Virginia. One of our peaks is getting taller while the valley is getting lower. (07270613)

Here the visitor seizes on to the idea presented in the question posed by the researcher that parts of the Colorado Plateau have been lifted as much as 10,000 feet above sea level. She scans her knowledge for instances of land rising, and recalls that "The same thing is happening in Virginia", accessing her familiar-place knowledge. She recalls that erosion from streams has been cutting the landscape, which she describes as "streams pushing down," and that "one of our peaks is getting taller while the valley is getting lower." Further evidence of her bootstrapping familiar-place knowledge appears earlier in her interview when she is asked what the landscape looked like at the time the layers in the mesa were formed, to which she replies "It was probably very hilly, with vegetation." Later, when asked what the area looked like during the time the trees grew, she replies "Probably more like regular mountains." She answers three out of five of the interview questions with references to mountains or hills, so it seems likely that the visitor lives near, or has intimate knowledge of, a mountainous region of Virginia or its foothills.

One other interesting sub-theme which emerged from the data and may be linked to familiar-place knowledge is the supposition by 10 (12.5%) of the visitor groups that the erosion of the landscape at PEFO was caused by glaciers, which is contrary to the normative position. In one example, when a visitor from Indiana is asked how the landscape came to look the way it is today, she replies (F58) "I have no idea, but it is beautiful. Glaciers maybe, through the years." When asked how the trees got there, she explains: "Probably maybe ice pushed it down from the North…with the Ice Age maybe?" Then when asked about the uplift of the Colorado Plateau, her husband reasons: (M65) Volcanoes wouldn't have done it. Something about glaciers. Stuff was pushed down and ice moved over the area. (07280617) A visitor from Michigan reports "I guess I have to say glaciers. I don't know…" (07300637). Other visitor groups who surmised that glacial activity carved the landscape came from the Netherlands, Oklahoma, and Texas. Visitors from these last two states also provided biblical interpretations in conjunction with the ice age ideas. Visitors from Canada, however, explain:

F (35) Not like glaciers where we are from.
M (45) Yeah, there has never been **any** glaciers here. Everything **we** see is glacier affected.
M (12) If this would have been in Canada, we would have said glaciers. The world looks different, glaciers then erosion. (122270655)

This family from Canada uses their familiar-place knowledge to realize that the landscape at PEFO would look different than it does today if glaciers had been responsible, and concludes that glacial erosion was not the cause of the erosional patterns they observed. Visitors from other areas where ice and snow are common were not able to make that distinction, however, and so concluded that, since glaciation is an important erosional force in their familiar-place landscapes, it must also be an important erosional force at PEFO.

Visitors Build on Religious Explanations

The second most frequent theme that emerged from the data concerned the use of ideas from religious teachings as a base for bootstrapping knowledge. Eleven percent of visitor groups (n = 9) constructed knowledge from a biblical perspective, although the degree of influence that religious teachings had varied from fully pervasive to incidental. Of the nine visitors citing the Bible as a source of knowledge, seven of ten (70%) discussed Noah's Flood. For example, in response to the researcher's question on how the landscape came to look the way it does today a family group from Texas explained:

> (F16) Erosion, rain.
> (F15) We have a theory where the land was flooded and then it kind of went down. There's other possibilities…
> (F16) Noah's Ark. They found that in the Arctic, though…
> (F40) It's part of the Earth, darling…We were actually just talking about it on the way over here, and no one in our family was really like a rock lover person, but when you come and you see this, its amazing, and it gets you to thinking "What in the world happened to make it look like this." After the flood, you know, it settled, and we learned about how it looks like the little elephant skin, Mom was asking that on the last little section, so… (07290628)

At first the 16-year-old begins to give a normative explanation, but the word *rain* seems to cue her 15 year-old cousin, who begins to give a Biblical explanation centering around the land being flooded and then "going down," but she tacks on an additional statement of "other possibilities". Her cousin then cuts back in and explains that they are speaking of "Noah's Ark," but then hesitates as she adds, "They found that in the Arctic, though…" Both girls seem reticent to propose the biblical explanation to the researcher, perhaps because they were aware that she is a geologist. The mother then steps in, reassures the girls by saying "It's part of the Earth, darling…" tells the researcher how amazing the family thinks the landscape is, and continues to tell the Flood story by interjecting "After the flood, you know, it settled…" She continues to demonstrate the family's knowledge by proclaiming that her mother, also with the group, is engaged with the landscape, and that the family was learning from the interpretive signage by mentioning *popcorn weathering*, which is the subject of the placard at that stop.

The mother then assumes responsibility for answering questions from that point forward. To the query about the formation of the layers she replies: "Oh, good grief, I don't know. I think I still picture it as the Ice Age and then all that stuff melted and this was the bottom of the ocean…that's what I think!" At this point the visitor imagines "the Ice Age", which conflicts with the Flood picture she had been building upon, because she now sees an ocean bottom with the water from a melted glacier filling the landscape. When asked about how the trees got there she says:

> Well, that's something totally new, we're not sure. Unless before the whole flooding, I mean the freezing, and the asteroid, you got to throw that in there too, you know… I don't know, that's why we came here. We thought that it was just trees out here in the middle of the desert, its surprising, actually, when we came here it said Petrified Forest, but its so much more. You know I don't know what to say. This was just a spur of the moment trip for us, so we were thinking standing up, petrified trees. (07290628)

At this point the visitor seems to be conflicted. She began by using the biblical paradigm for an explanatory framework, but found it did not serve her to explain either the deposition of the layers, or the trees. However, all of her explanations rely on catastrophic events on shortened timescales, not slow processes taking place over long time spans. Even when asked what caused the uplift of the Colorado Plateau, this visitor suggested two catastrophic explanations: "Earthquakes, volcanoes maybe."

Within the religious explanation category, catastrophism on shortened timescales seems to be a sub-theme. One visitor from Arizona, who describes climate change through analogy with Israel, also discusses "New Orleans is still sinking…Something dramatic had to happen…but some got pushed up or there was a big sinkhole" (07280616) when asked about the uplift of the Colorado Plateau. Another family group from Georgia explains:

> (M45) Ok, well I think it was pushed up. Well, we're Christians, so we think it happened at the time that The Flood was, probably by a lot of the same processes that are involved in the scientific explanation, but more rapidly.
> (M12) 40 days.
> (M45) Well, over a year or so…
> (M12) Yeah.
> (F40) It rained for 40 days, but it took a long time for the water to go all over and recede…
> (M45) Well, during that time we had massive geologic changes. (07290633)

This family consistently adheres to biblical explanations throughout their interview, and all the events they discuss take place on shortened timescales, but the actual length of those timescales vary with individual members of the group, with the mother acting as moderator to guide the family into a consensus. When asked what the area looked like at the time of the formation of the layers, the family had the following to say: "(M45) I think the layers were formed as ocean floor, but quickly, as a result of The Flood, kind of like Mount Saint Helens." Again, a catastrophic event is referenced as a modern-day analog to support the religious paradigm.

Visitors Superimpose Past Landscapes on Modern Ones

Another theme that emerged from the data is that visitors, while trying to make sense of the landscape, imagine they are seeing landscapes from millions of years ago still expressed in present day. For example, a visitor from Oklahoma, when describing how the landscape came to look the way it does today, says:

> (M55) It looks like there was a big inland sea here. If I just look around I can see the shoreline and then it looks like this flat area could be the bottom of the sea. (07290627)

When asked about the time of layer formation he continues:

> Ah, well, once again I would say that… traveling here from New Mexico, when I see the mesas they look like the surface of the land and this is a big inland sea. (07290627)

This visitor recalls what he sees during the drive from Oklahoma to PEFO through the state of New Mexico. In this case the ideas he is bringing to make meaning of this landscape are not familiar-place knowledge. He does not necessarily have intimate knowledge of New Mexico; he made an observation as he drove through that it looked like the flat tops of the mesas were land surfaces and the "bottom" that he was driving on could be the bottom of the sea. It is even possible that he did not have this idea before the researcher asked the question, but constructs the idea on the fly as he is attempting to answer and he observes, "It looks like there was a big inland sea here". As he traces the shore of the sea in his mind's eye, it may have triggered the memory of the recent drive through New Mexico and provided a mental model that he could use to explain the landscape.

When asked what how the trees got there, a visitor from Missouri had the following to say, (F65) "I think they washed from someplace; I just don't have any idea from where, because there sure doesn't seem to be any forests very close." (12270661) This example is from a visitor who also uses a biblical paradigm for her conceptual framework. Even when asked about the uplift of the Colorado Plateau, it is clear that all her ideas are being constructed from this point-of-view, for example:

> (F65)So do you mean that part of it is like sea level?
> *(I) No, its 10,000 feet above sea level.*
> (F65)I guess I'm really not understanding the question because, it isn't all...that whole big area isn't all at 10,000 feet?
> *(I) Pretty much.*
> (F65)It **is** at 10,000 feet. Why do you think it has been lifted to that? I'm just not following.
> *(I) Well, because there are fossil remains in these beds of fish and other sea creatures, so this has been under the sea at one time.*
> (F65)Right...it has to have been under the sea at one time and now its 10,000 feet in the air. It had to have been at sea level, or simply covered by the flood. That would be what I would think.
> (M70) The ninth chapter of Genesis says God broke up the foundations of the deep. That's when I think it happened.

Once again there seems to be a connection between a shortened timescale, shown by the imposition of past landscapes onto modern ones with the statement "there sure doesn't seem to be any forests very close" and a biblical base for bootstrapping knowledge construction.

Visitors Patch Together Bits of Information Gleaned from the Media

Just as visitor knowledge bases vary widely, so do their sources of interpretive information. Some of the places from which visitors gather ideas are media sources such as television, movies and books. Visitors sometimes take an idea garnered from a mediasource and integrate it with other information to come up with a concept of landscape formation. For example, the visitor from Oklahoma who was able to visualize an inland sea in the present-day landscape continued with this idea:

> (M55) Ah, well, once again I would say that… traveling here from New Mexico, when I see the mesas they look like the surface of the land and this is a big inland sea. I saw something on NOVA that kind of explained that inland seas were kept in place by glaciers, then the glaciers let them leak through and that led to the creation of things like the Grand Canyon. (07290627)

The visitor observed that the tops of the mesas on his drive from New Mexico were flat like a shore at sea level. He noticed that the bottom of the mesas were also flat and visualized a shoreline stretch along the tops of the mesas, with the bottom of a big inland sea. Then he recalled a NOVA episode he had seen, *Mystery of the Megaflood* (2005), which describes a catastrophic flood event that carved out the Channeled Scabland of eastern Washington about 15,000 years ago when Glacial Lake Missoula burst through the ice dam that held it. The visitor uses the information he remembers from the program as justification for the existence of the inland sea he is visualizing, and is satisfied with his mental model. Once again, this visitor is also using a biblical paradigm to construct knowledge, although it remains obscure until his answer to the Colorado Plateau uplift question when he replies, "Well, that's the big question, big question, I think either through millions of years or there was a Great Flood." (07290627)

Another media source is the interpretive information available at PEFO and at other places of interest in the area. One nearby attraction that seems to influence visitor thought is Meteor Crater, an impact site about 60 miles west of PEFO. A family group from Arizona describes the following:

> (M45) The trees, according to some of the other stops in this area, were probably growing upon one of the layers and something like the Meteor Crater cataclysmic event caused the extinction of the trees and animals, and they in turn got covered over by more dirt and wind and water. (07280623)

This visitor recalls that scientists believe the effects of an impact event killed the dinosaurs. He sees the trees in the landscape before him and seeks a reason for them to have died. Since PEFO and the surrounding area are a rich source of fossilized bones as well as petrified wood, it seems to the visitor that there should be a common link. Besides the proximity of Meteor Crater, which the visitor may or may not have patronized, the nearby town of Holbrook displays large dinosaurs at various locations throughout the town, as do other businesses along Interstate 40 -- the main road to PEFO. Combining the ideas of (a) dinosaurs co-existing with the trees at PEFO, (b) dying at the same time, (c) the proximity of Meteor Crater, and (d) the knowledge that an impact has often been cited as responsible for the deaths of dinosaurs; the visitor combines these pieces of knowledge to come up with the new concept that the impact event at Meteor Crater killed the trees that are now petrified at PEFO.

Visitors Have Problems Visualizing Climatic Change

Another theme that also emerged is that visitors have a hard time visualizing climate changes over geologic time. For example a couple from New York, while answering how the landscape came to look the way it does today, had the following discussion:

(M30) Ahm, what I understood is that it was an ocean millions of years ago that dried up, and then those trees are ancient redwoods.
(F25) I think it was a forest first, it was an ancient forest first, and then there was a meteor, an explosion, and then it became ocean.
(M30) So some big glacial melt or something.
(F25) Yeah, maybe it could have been because how else could it be?
(M30) A big climate change...
(F25) Maybe flowing water brought them...like maybe it was an ocean and then it just dried out and brought in this huge...
(M30) I visited this park when I was five or six years old, but the sun was hot and bright, and the palette was totally different. It's interesting, it's much more subdued but you can still see the layers. (12280670)

This shared construction of knowledge does not seem to have a common base from which to grow. There is no mention of either place or interpretive information for the couple to begin co-constructing a framework on, neither is there an observation from which to build. Consequently, what is constructed seems to be two disjointed conversations that do not merge at a common point. The male says the area was an ocean first, then became a forest, which the female deconstructs and reconstructs to say it was a forest, then a meteor exploded and it "became an ocean", implying that the trees died at that time and were petrified at the bottom of an ocean. The male attempts to build on this idea, imagining that a glacier melted in a "big climate change," but the female switches to thinking now that flowing water brought in the trees, dumped them in the ocean, and then the ocean dried up and the trees were left. At this point, the male changes the subject and begins to talk about the colors in the layers.

In a second example, a visitor from California replies to the question of how the trees got there, (M35) "Well, there's not that much vegetation, maybe pollination from wind. Whatever grows here has to be able to handle pretty dramatic climate. Hot summers, cold winters, things like that." (12270653) But then he changes his conception when asked what the area looked like when the trees grew and replied, "The landscape was different then than now, I'm not real sure, perhaps there was a large rainforest here. Something for the dinosaurs to eat." At first he equates the time of tree deposition to modern-day landscape, then decides that the landscape was more tropical when the trees actually grew, perhaps recalling other interpretive information, but even then he admits that he can not really visualize what the area must have looked like.

A visitor from Georgia solved the problem of not being able to fit what she knows about tree growth into her mental model of what the area looked like a different way. She says, "(F35) I don't think these trees grew here, I think these trees grew someplace else in a different climate. I think its probably too harsh, too dry, too rugged a climate for trees of this size…" (07270605) rather than shift her mental model of what the climate was like during the time of tree growth, she decided that the trees grew in a different location with suitable climate for growing large trees. In this way she was able to retain her current mental model of the area as it appears today, "harsh…dry…and rugged."

Finally, a visitor from Texas with familiar-place knowledge had the following to say when asked what the area looked like at the time the trees grew, "(F40) I don't know, I just read where it said

it was a swamp, but that's hard to imagine. I live in the swamps, and this doesn't look anything like Louisiana-Texas marshland to me, at all. So that's what's difficult. It seems like it must have been something major to create this amount of erosion, maybe just time. We aim to find out." (07290628).

Conclusions

This project investigates visitors' ideas about geological processes, features, and history at Petrified Forest National Park in northern Arizona, a place renowned for its colorful badlands and fossil wealth. Volunteer subjects explained the formation of the landscape, described the depositional environments coded in the rocks (including the origin of fossil logs) and accounted for the present high elevation of the Colorado Plateau. In the absence of accurate geological understanding of the landscape, visitors to Petrified Forest National Park combined their perceptions of the landscape before them with *familiar-place knowledge* gained through experience with other places, as well as other sources of interpretive information to make meaning of the geology. Qualitative analyses indicate that visitors variously make meaning by (1) relating landscapes to familiar places, (2) building on religious explanations, (3) superimposing past landscapes on modern ones and (4) patching together bits of information from media sources.

Visitors have great difficulty visualizing what the landscape must have been like during the time of formation of these features. In particular, visitors have difficulty with transforming the present landscape into a more vegetated, wetter picture. Although most visitors realized that water played an important part in the PEFO formation story, they were not, in general, able to visualize a large river system in place of the now arid landscape. Instead, most were likely to see the area at Blue Mesa as having formed in a marine environment. Several visitors also envisioned the landscape to be a consequence of glacial erosion, while others cited the biblical description of Noah's flood.

When asked about the landscape during the time of tree growth, visitors exhibited confusion about the appearance of the landscape, appearance of the trees, and where the trees actually grew. Visitor descriptions of the landscape during tree growth varied wildly, with images of tropical rainforests, swamps, woodlands, pine forests, conifer forests, mixed forests, dense forest and patchy forests all being described.

Most visitors attributed the height of the Colorado Plateau to some type of tectonic activity, which included plate tectonics, earthquakes, continental movements, mantle processes, and pressure under ground. Volcanism was also mentioned, but not as frequently as was tectonism.

Most visitors reported that time played an important role in the geologic story at PEFO, but the length of that time varied a great deal both between and within visitor groups. Shortened time scales seem to be linked with ideas of catastrophism in visitors who built upon biblical paradigms.
Visitor sources of knowledge, reported or inferred, varied widely. These sources include the PEFO visitor centers, PEFO documentary movie, evidence or direct observation, familiar knowledge of other places, interpretive signs, readings, religious teachings, geology classes,

family discussions, television programs or popular movies, and information gathered from other parks or attractions in the area. Most visitors reported stopping at a visitor center upon entering the park. Additionally, 44% of visitor groups watched the park documentary. The source of knowledge utilized next most frequently after this was familiar-place knowledge, with biblical teachings figuring prominently as well.

Familiar-place knowledge, used in combination with observation or other interpretive information, led to both normative and non-normative geologic concept formation. Visitors use their visions of familiar places as pieces of knowledge which they then mix with observations and knowledge pieces from other sources to render a mental model of what the past landscape looked like, providing evidence that diSessa's model of conceptual change, *knowledge in pieces*, may be applicable to the domain of geology as well as physics.

Another way in which visitors were observed to make meaning is through the restructuring of their mental models of what the landscape should look like. When visitor observations did not fit the mental model of what they thought the landscape must have looked like long ago, visitors either appear to have adjusted their mental model to fit their observations, or adjusted their observations to fit the model.

The degree to which present-day landscape influenced visitor conceptions was surprising to the researcher. It seems very probable that if the study had been conducted near a flowing river, for example, visitors would have been much more likely to visualize a large river system running through the area. Similarly, trees anywhere on the landscape would likely have made visualization of lush vegetation more probable. The aridity and lack of vegetation in the present landscape, however, served as real barriers to normative geologic concept formation in the case of many visitors.

Recommendations

Visitors Have Problems Visualizing A Large River System In The Area

When designing interpretation for Petrified Forest National Park, I recommend that PEFO staff use visitor reliance on familiar-place knowledge to help visitors build normative concepts about PEFO landscape formation (see Table 2). For example, during questioning about the formation of the layers at Blue Mesa, visitors repeatedly answered in a manner that showed they had no clear idea of what the environment at the time looked like. One way to help visitors visualize the type of river thought to have existed at PEFO would be to build part of an interpretive display around a *modern analog*, a real river that exists on Earth today and closely resembles what the Chinle River system is thought to have been like, a *braided river*. A good example of a modern-day braided river is the Bramaputra River on the Indian subcontinent, while a smaller example is the Fraser River of British Columbia in Canada. In addition, the depositional environment of the purple, blue and gray mudstone layers of the Blue Mesa Member and Jim Camp Wash beds of the Sonsela Member, was the flood plain for this large river system, and under fresh water most of the time. This modern-day braided river system analog could be brought to life in the visitor center with a short video clip of the real river complete with sound. A 3-D map model could also be installed, perhaps patterned after Ronald Blakey's paleoenvironmental maps in use by PEFO in some of the interpretive literature.

Table 2

Interpretation Recommendations Based on Visitor Conceptual Problems and How Visitors Make Meaning

How visitors make meaning	Visitor Conceptual Problems	Interpretation Suggestions
Visitors relate landscapes to familiar places	Visitors have problems visualizing a large river system in the area.	Use modern-day analogs • Brahmaputra River in Asia provides an example of a large *braided river system* similar to the one thought to have deposited the Chinle Formation; Fraser River in British Columbia, Canada may provide another example • Mississippi River may provide examples of crevase splays and over-bank silt deposition
Visitors build on religious explanations	Visitors have problems visualizing a log jam of trees.	Be aware of *catastrophism* when providing interpretations • "flood" brings ideas of Noah's Flood to the forefront; portray log jam events as a recurring, natural process. Use analogs from Pacific Northwest
Visitors superimpose past landscapes on modern ones	Visitors have problems visualizing flora and fauna of the Triassic.	• Provide a tactile walk-through exhibit at the visitor center to show visitors what the environment was like. Recreate humidity levels, sounds (e.g. bees, running water), animals, and trees in life-size. • Use real modern analogs for plants (e.g. Sago palm, spruce, horsetail, club moss)
Visitors patch together bits of information gleaned from media sources	Visitors often patch together bits of information and come up with non-normative conclusions.	Provide additional forms of interpretation media for visitors • Visitors already enjoy the park documentary; perhaps audio devices similar to the audio sticks found at Sunset Crater National Monument and many art museums could be programmed with audio descriptions of various features in the park. These sticks could be "rented" at the gate or visitor center, and visitor could be partially reimbursed for their return. • Solar-powered video clip displays could be installed at selected visitor pull-outs
Visitors relate events to human timescales.	Visitors have problems conceptualizing the length of geologic time	Install a PEFO version of the *Trail of Time* walking timeline. Consider installing two trails, one emphasizing the geology found in the park and the other (at a different scale) the anthropological resources found there.

Visitors Have Problems Visualizing A Log Jam Of Trees.

The jumbled appearance of the logs preserved within the strata at Blue Mesa is also puzzling to visitors. Perhaps a modern-day logjam analog can be found in the Pacific Northwest such as those occurring during the storm incidents at Mount Rainier National Park and other areas in the winter of 2006 and spring of 2007. It is also recommended, however, that when using flooding incidents as analogs they be portrayed as naturally re-occurring events and not one-time disasters.

Visitors Have Problems Visualizing Flora and Fauna of the Triassic

Ideally, proposed by some park staff, an environmental recreation of the area in which park visitors could walk through and experience a simulated Triassic landscape complete with elevated humidity levels, sounds, and life-size flora and fauna reproductions would serve to cement a picture of the environment in visitors' minds, particularly if touching of the exhibits was encouraged. The picture that visitors construct of the Triassic depositional environment will necessarily include images of the trees and plants that grew there. Use the landscape filmed in *Timeless Impressions* (2004) as a backdrop to provide internal consistency to the interpretive story. In addition, Mary Sundstrom has painted some wonderful paleolandscape recreations that could be utilized, with approval from paleoenvironmental researchers already working in the park.

PEFO staff can carefully build the paleoenvironmental picture by including replicas of modern descendants of flora whose fossils are preserved in the park. If this is not possible, perhaps an area with life-size examples of selected flora and fauna in an exhibit setting could be provided. Another idea would be to set aside a small garden area where modern-day descendants of the plants found at PEFO during this time such as Sago palm, spruce, horsetail and club moss, could be cared for and available for visitors to touch.

Visitors Often Patch Together Bits of Information and Come Up With Non-normative Conclusions

Visitors already enjoy the park documentary, and may respond equally as enthusiastically to talking sticks similar to those found at Sunset Crater National Monument. Talking sticks are audio devices found commonly in art museums. They come pre-programmed with short verbal clips of information about particular items of interest. The visitor punches in the numerical code for a particular item, which is displayed at the sight, and the audio recording is called up. Visitors do not have to listen to every station, nor do the need to proceed through the sights in numerical order. This technology can also be programmed in a series of foreign languages for tourists. These audio sticks could rented at the main gate or visitor center, with a substantial reimbursement given when the audio stick is returned at the exit. In addition to the talking sticks, select pullouts could be outfitted with solar-powered video clip displays showing paleoenvironments, faunal recreations, or recreations of ancient cultural scenes.

Visitors Have Problems Conceptualizing the Length of Geologic Time

Since visitors to PEFO seem to have a great deal of difficulty grasping geologic time, another project that PEFO staff may want to consider implementing is a Petrified Forest National Park version of the *Trail of Time* project being designed and implemented at Grand Canyon National Park (GCNP). The trail at GCNP is being installed along the south rim of the Grand Canyon, and

will describe geologic events that happened from the deposition of the oldest layer seen to the cutting of the canyon on a scale of one meter equals one million years. A version of this design could be modified to fit within PEFO boundaries, perhaps at the Blue Mesa hiking trail or other location deemed suitable by the staff, and serve to clarify some of the time-related issues visitors are known to possess. PEFO should consider installing two trails, one emphasizing geology at geologic timescales, and the other emphasizing the archaeological story at human timescales. The two should be melded so that visitors who walk both are able to see the vast difference between the two scales.

Visitors to PEFO have a great deal of difficulty imagining the depositional landscape of long ago and grasping geologic time. *Familiar-place knowledge*, garnered through experience with another place and applied to make meaning of the PEFO landscape, should be leveraged through the use of carefully coordinated modern-day analogs to give visitors a feel for what the land was like long ago. In addition, a PEFO Trail of Time outdoor exhibit would give visitors who chose to walk it a new perspective of geologic time scales and further inform them about landscape formation in the park. This research has added valuable insight to our understanding of how non-geologists make meaning in a natural park setting. In addition, it has provided specific examples of geologic concepts visitors have problems understanding. I highly recommend the implementation of similar research studies using this methodology in other National Parks

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