Informal Geoscience Education on a Grand Scale: The Trail of Time Exhibition at Grand Canyon

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ABSTRACT

The Trail of Time exhibition under construction at Grand Canyon National Park is the world's largest geoscience exhibition at one of the world's grandest geologic landscapes. It is a 2-km-long interpretive walking timeline trail that leverages Grand Canyon vistas and rocks to guide visitors to ponder, explore, and understand the magnitude of geologic time and the stories encoded by Grand Canyon rock layers and landscapes. As one of a new generation of geoscience education exhibits, the Trail of Time targets multiple cognitive and affective levels with accurate content, active geoscience inquiry and interpretation, and place-based cultural integration. It developed as an outgrowth of sustained geoscience research funded by the National Science Foundation, with scientists as the conceivers and coordinators of the project. It benefits from a high level of synergy with the National Park Service interpretation division, as well as extensive on-site and off-site evaluation of pedagogic effectiveness in the outdoor informal science environment. The Trail of Time will impact many of the five million annual visitors to the National Park. Associated cognitive research on public understanding of "deep time" offers opportunities to inform more effective geoscience pedagogy for informal and formal educational settings.

INTRODUCTION

Informal geoscience education is being reinvigorated at many parks and museums, in part in response to greater societal awareness of global change and natural hazards. The next generation of interpretative geoscience exhibits and programs must be effective at multiple cognitive levels because of the diverse audience (e.g., National Park Service, 2002) that takes advantage of such programs and exhibits, and their design should be a team effort combining the expertise of geoscientists, cognitive scientists, designers, evaluators, and specialists in visitor studies and interpretation. The Trail of Time exhibition at Grand Canyon National Park, funded by the Informal Science Education Program of the National Science Foundation, exemplifies such collaboration by including academia, the private sector, and the National Park Service. Under construction and scheduled for completion in 2009, the Trail of Time will be the world's largest interpretative geoscience exhibit at one of the world's signature geoheritage places. This park is visited by about five million people each year (Littlejohn and Hollenhorst, 2004), many of whom are motivated by their first sight of Grand Canyon to formulate questions about the rocks and landscapes. The goal is to enable Grand Canyon visitors to construct both an accurate understanding of and a visceral feeling for geologic time and Earth history, by coupling cognitive and kinesthetic learning (Gyllenhaal, 2006; Perry, 2002), as they traverse a walkable time line laid out along a popular trail at the South Rim of Grand Canyon.

A grasp of the magnitude of geologic time is the foundational knowledge needed to construct an understanding of many aspects of our planet, including the evolution of life and the grandeur of nature (Darwin, 1859; Zen, 2001; Dodick, 2007). A temporal context is also needed for many issues related to sustainable stewardship of our planet (Trend, 2000). Learning to correctly interpret the physical evidence for the great ages of the Earth and the universe is found within the national science education standards (AAAS, 1993; NRC, 1996) that, in turn, inform most state and local standards.

Figure 1. Rendering of the Main Trail: small disks are spaced at one-meter (one million year) intervals, and labeled medallions (inset) are deployed every ten meters (ten million years).

But common acceptance and understanding of geologic time are chronically undercut by the scarcity of Earth science courses at the high school level (Barstow et al., 2002) and by continuing sociopolitical opposition from young-Earth creationists. Misconceptions about the scale and sequence of geologic time have been richly documented among teachers and students of all ages (Ault, 1982; Gould, 1987; Marques and Thompson, 1997; Trend, 1998; 2001a; 2001b; Dodick and Orion, 2003a; Libarkin et al., 2005) and similar misconceptions are also held by members of the general public (Hayward, 1992; 1993). Opportunities to address these misconceptions through interactive and engaging informal education abound, but there is little research about how this can be done most effectively.

National Parks and Monuments in the United States are primary venues for informal science education; they typically offer exhibits and displays, interpretative programs such as hikes led by Park Rangers, and the diverse publications distributed or sold at visitor centers. In many National Parks, interpretative activities have focused more on biological and social sciences than on geoscience, but the situation is changing (NPS Advisory Board, 2001). Parks serve as dynamic learning laboratories where visitors can readily explore Earth materials, landforms, processes, and history. It is difficult to imagine a better place for informal geoscience education than Grand Canyon, where panoramic landscapes and rock exposures have long inspired explorers and visitors to inquire about the processes that emplaced and sculpted them (Pyne, 1998).

The essence of the Trail of Time exhibition is an interpretative trail (Figure 1) that will be marked with inset bronze disks at every meter of its length (and larger numerically labeled medallions every 10 meters), each meter representing one million years of Earth and life history.

The main Trail of Time extends about 2,000 meters, corresponding to the nearly 2,000 million (1.84 billion) years of history encoded in the Proterozoic and Paleozoic rocks of the Grand Canyon. Amazingly, the geologically recent carving of Grand Canyon by the Colorado River is encompassed in the first six steps of the Trail. This analogical device is a scaled-up and permanent version of similar timeline analogs that are commonly used by educators to teach quantitative geologic time (e.g., Brandt et al., 2007). The Trail of Time makes use of existing paved and fully accessible trails perched along the South Rim between Yavapai Observation Station (the Park's recently remodeled geological museum; National Park Service, 2007) and Grand Canyon Village, where most visitor amenities are sited (Figure 2). This central location is visited by more than 65% of those who come to Grand Canyon National Park (Littlejohn and Hollenhorst, 2004).

The primary "exhibit" is the Grand Canyon itself; the Trail of Time is designed to help visitors understand the concepts of "deep time" (McPhee, 1981) and geological change that are manifested by the Grand Canyon, as well

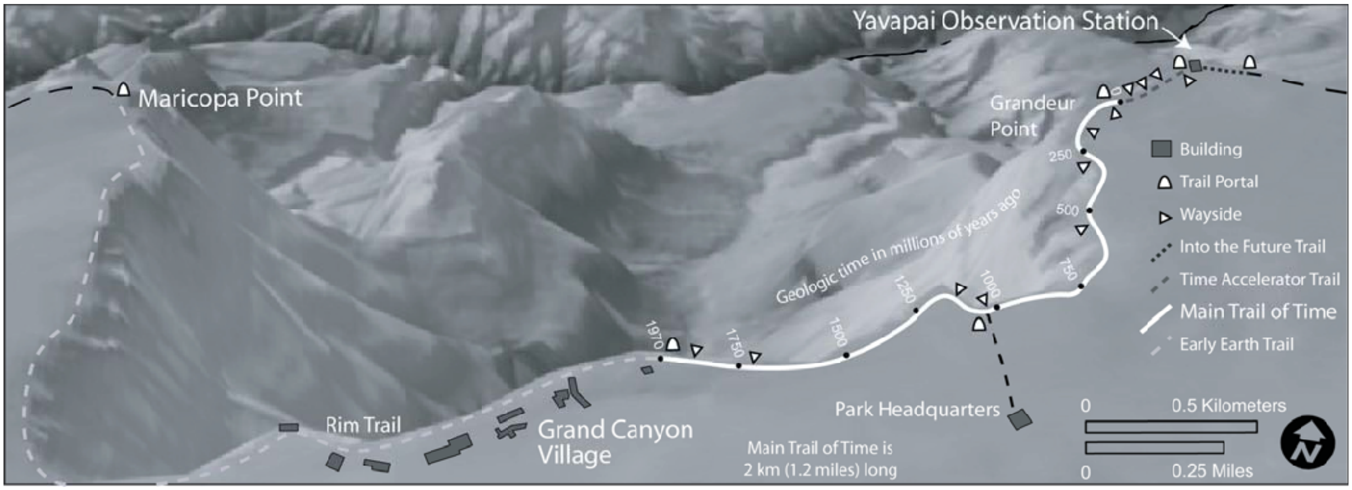

Figure 2. Synoptic map of the Trail of Time Exhibition, showing the planned configuration of Trail components and their relationship to South Rim geography and Park facilities.

as the processes of scientific inquiry that have yielded this knowledge. Various components of the exhibition support these objectives including the Trail itself, numerous interpretive wayside exhibits along the trail, a walking guide and brochure, and a 140-meter "Million Year Trail" section, which unpacks the most recent one million years of Earth history to help visitors gain a deeper appreciation for how long each 1 meter (1 million year) step along the main Trail really is. Along this segment of the trail, the time scale increases by a factor of ten every few tens of meters: from one year per meter at the start to 100,000 years per meter at the end, where it merges into the main Trail. This "time accelerator" is designed to help visitors shift their temporal perspectives from a personal time scale (years) to historic time scales (tens and hundreds of years), then to archaeological time scales (thousands of years), and finally to the million-year geologic heartbeat they will pace for the next 2,000 steps along the main Trail. An "Into the Future Trail" will lead visitors several centuries forward in time at one year per meter, challenging them to ponder and compare the futures of the Grand Canyon, the Southwestern natural and cultural environment, and humanity.

Ultimately, the main Trail of Time will be built out to the length of 4.56 kilometers in order to encompass all of geologic time; the segment beyond the 2 kilometers (1.84 billion years) of the main Trail, will be referred to as the "Early Earth Trail," accounting for the greater proportion of Earth history that predates the oldest rock in the Grand Canyon. About 12 interpretive wayside exhibits will be spaced along the trail at locations that correspond to major geologic events in Grand Canyon history: such as canyon carving (at trail marker 6 Ma), formation of the Kaibab Limestone that caps the South Rim (where this layer meets the timeline at 270 Ma), the Cambrian explosion of life at 540 Ma, the Great Unconformity (Powell, 1895/1987), and the formation of the continental crust of the Southwest (1750 Ma). Concise walking guides (Figure 3) and other brochures related to Grand Canyon geology will be made available at numerous points along the Trail and in Park museums.

To further help visitors connect the rocks exposed vertically in the canyon walls to their genesis in geologic time, an intriguing specimen from every named rock layer that occurs in the Grand Canyon (30-40 in total) will be mounted trailside at the point in the timeline corresponding to its age, and labeled accordingly. Visitors will touch and examine up close the same rock types that make up the distant spectrum of layers viewed from the South Rim. In this way, visitors will be able to better integrate the "vertical" (the actual strata which compose the Grand Canyon) and "horizontal" (the timeline itself) components of time which compose this outdoor museum exhibit. The physical Trail of Time exhibition will also be supplemented with an online Virtual Trail of Time (http://epswww.unm.edu/TrailofTime) which, as materials are developed, will provide additional Grand Canyon-based geoscience education resources for continued intellectual engagement in both formal and informal learning environments.

People have lived in the Grand Canyon region for at least 13,000 years (Coder, 2006). No fewer than ten modern American Indian nations (Havasupai, Hopi, Hualapai, Kaibab Paiute, Navajo, Paiute Tribe of Utah, White Mountain Apache, Yavapai-Apache, San Juan Southern Paiute, and Zuñi) are traditionally associated with the Grand Canyon. In addition, the Moapa Band of Paiute Indians and Las Vegas Paiute Tribe, both in Nevada, also claim such an association. Over centuries to millennia of place-based empirical observation, reasoning, and intergenerational transfer (largely through oral history), indigenous peoples have built rich systems of knowledge variously called traditional ecological knowledge (Inglis, 1993; Cajete, 2000) or simply indigenous or local knowledge (Riggs, 2005). These knowledge systems have drawn interest from mainstream science (e.g., Krajick, 2005; Couzin, 2007) and also inform the design and implementation of cross-cultural science teaching (Cajete, 1994; Nelson-Barber and Estrin, 1995; Aikenhead, 1997, 2001; Semken and Morgan, 1997; Snively and Corsiglia, 2001; Riggs and Semken, 2001; Semken, 2005; Gibson and Puniwai, 2006; Chinn, 2006). This knowledge is evolving, relevant, and applied by a significant number of the permanent inhabitants of the lands surrounding the National Park.

Indigenous knowledge focused on Earth systems and processes is termed *ethnogeology* (Murray, 1997; Riggs and Semken, 2001; Semken, 2005). The Trail of Time is intended to be as culturally integrative as

Figure 3. Example of a concise walking guide developed and evaluated for the Trail of Time.

possible, in order to more effectively engage diverse regional groups. Therefore, an objective of the project is to incorporate locally situated ethnogeologic concepts relating to Earth materials, landforms, and processes at Grand Canyon within the exhibition (primarily in the Virtual Trail of Time and online or printed supplements). Only limited aspects of the ethnogeologic and related knowledge of Native peoples associated with Grand Canyon have been documented (e.g., Semken and Morgan, 1997; Stoffle et al., 1997; Hirst, 2006), and ongoing research in this area as part of the Trail of Time project proceeds deliberately and carefully in order to fully protect culturally sensitive information.

One indigenous ethnogeologic concept that has been integrated into one of the wayside interpretive panels along the "Million Year Trail" segment is a cyclical perspective of time (Brown, 1982; Bol, 1998). The cyclical time model is central to the traditional living patterns of many American Indian societies (Bol, 1998). It contrasts with the linear "time's arrow" (Gould, 1987) model of the progression of time, encoded in the vertical dimension of deposition and downcutting observed in Grand Canyon, and horizontally in the Trail of Time and similar timeline analogs. However, the cyclical model also complements the linear model as represented by the rhythmic nature of certain natural processes, such as seasonal or other periodic variations in sediment deposition and tree growth. This idea is illustrated at another "Million Year Trail" wayside display, with the display of a large specimen of rhythmically banded travertine from a Grand Canyon spring and a cross-sectional image of a log from northern Arizona, showing growth rings.

Another ethnogeologic principle that informs Trail of Time content development is that of duality in nature, which interprets natural processes as interactions between two dynamic and living systems, Earth and Sky (Williamson and Farrer, 1992; Semken and Morgan, 1997; Aronilth, 1994). The model is essentially equivalent to the description of endogenic and exogenic geological processes in Earth system science (Semken and Morgan, 1997; Semken, 2005), and offers a culturally relevant framework for describing the interacting processes of deposition, burial, uplift, and erosion that formed the Grand Canyon landscape.

The Trail of Time exhibition is part of Grand Canyon National Park's efforts to achieve an enhanced and integrated geoscience interpretative program. As such it supports, builds on, and complements other existing Grand Canyon geologic interpretation, including the Yavapai Observation Station and Park publications. The concept is fully exportable to other Parks, and will be easily adaptable and able to be modified to complement their unique geologic settings and resources.

VISITOR STUDIES

Roughly 75% of Grand Canyon visitors are part of family groups (Littlejohn and Hollenhorst, 2004), making it especially important to facilitate a range of informal learning activities. These visitors stay for varying durations, from a few hours to many days, and engage with the Canyon in a range of ways, from peering over the edge to hiking into its depths. The challenge for the Trail of Time team is to design an exhibition that can be understood by visitors who engage with it for only a few minutes, as well as those who walk its entire length and interact in rich and meaningful ways with a multitude of interpretative media. Visitor studies experts and geoscience educators on the Trail of Time team have used a combination of literature reviews, educational research studies, and evaluation studies to meet that challenge.

Evaluation work for the Trail of Time began in 2004 with an extensive front-end/formative study using preliminary mock-up designs to test initial concepts with visitors to the South Rim (Gyllenhaal and Perry, 2004; also available from the Trail of Time website). One of the most significant results of this study indicated that visitors find it challenging to reconcile the vertical (canyon walls) and horizontal (timeline). This continues to be an important consideration and one the project team is carefully addressing.

Following up on the findings from the front-end/formative study, the project team and a group of about 30 Grand Canyon experts and community stakeholders met for a two-day on-site retreat in fall 2006. An important outcome of the retreat was the formulation of the Big Idea (Serrell, 1996) for the project: *The Trail of Time - an interpretive walking timeline trail - focuses on Grand Canyon vistas and rocks to guide visitors to ponder, explore, and understand the magnitude of geologic time and the stories encoded by Grand Canyon rock layers and landscapes*. This Big Idea has provided an important framework and foundation for all subsequent development and evaluation work.

An integral part of Trail of Time development, formative evaluation of evolving iterations of prototype markers, displays, and brochures has been conducted over the past four years, both off-site and on-site at the South Rim. Each test has been documented in a written "Evaluation Brief" (available on the Trail of Time website). These briefs summarize findings on a wide range of topics, such as:

- specific wording found to work best for the labeled time markers (e.g., findings indicated the importance of including the word “Timeline” on each);
- visitors' understandings of the concepts on numerous interpretive wayside exhibits (e.g., it proved difficult to portray the key concept of Colorado Plateau uplift on a panel that was at once accurate and readable at a glance); and
- how visitors understand and make sense of large numbers (e.g., it proved most effective on markers to use the word “million” instead of numbers with six zeros, but also to use zeros instead of the word “hundred” or “thousand”).

Based on the findings from the ongoing formative evaluation, interpretive messages have been focused and refined, texts have been clarified and sharpened, and interactive experiences honed.

An important goal of the Trail of Time is to facilitate collaborative learning within family and other social groups (Leinhardt, Crowley, and Knutson, 2002). Supplying visitors with factual information such as the ages of Grand Canyon rocks and the Earth itself is one important objective, but a broader and more ambitious objective is to engage visitors with a large-scale analogy or metaphor for geologic time, so that they can themselves construct a richer understanding of and appreciation for the magnitude of "deep time." Using a framework designed to promote and enhance active physical, intellectual, social, and emotional engagements (Perry, 1989) with the vast spatial and temporal scales that transcend human scales, the Trail of Time is designed to inspire visitors to reflect on, make more tangible, and in many instances revise, their own internalized understanding of how human time scales relate to geologic time scales. Many educational interventions have been created to address geologic time (Hume, 1978; Rowland, 1983; Ritger and Cummins, 1991; Metzger, 1992; Everitt et al., 1996; Spencer-Cervato and Daly, 2000; Reuss and Gardulski, 2001; Nieto-Obregon, 2005; Brandt et al., 2007), but there is nothing comparable in scale or scope to the Trail of Time.

In most informal science ventures, visitors arrive with a great range of understandings of and experiences with the topic being portrayed. This diversity of entrance narratives (Doering and Pekarik, 2000) could not be greater than among visitors to the Trail of Time. One of the challenges of the Trail of Time formative evaluation is to maximize the potential of the exhibition for as many visitors as possible. To this end, formative evaluation will continue to guide and inform development decisions as the Trail inches closer to final design and ultimately fabrication and installation, after which time a thorough summative evaluation will be conducted.

The purpose of the final summative evaluation will be to assess the ways in which and extent to which visitors make sense of the Trail, and use it to further their understandings of "deep time" and Grand Canyon geology. When visitors display a wide range of understandings of an exhibit or concept, a knowledge hierarchy is a useful framework for dealing with such variation (Perry, 1989; 1993). A knowledge hierarchy assumes that there is a content-based internal knowledge structure in the subject of any exhibition - in this case "deep time" - but that most of the general public has alternate ways of connecting to and understanding the topic. A knowledge hierarchy emerges from visitor data in the context of expert knowledge, and is often described as the intersection of the experts' and visitors' organization and understanding.

As data are gathered during the summative evaluation, knowledge hierarchies will capture the range of ways visitors use the trail to make sense of their visit and answer their questions, and will document visitors' personal conceptual journeys as they evolve their understandings and further develop their "islands of expertise" (Crowley and Jacobs, 2002)

COGNITIVE RESEARCH STRATEGIES

The Trail of Time project also provides opportunities for more basic research into public cognition of quantitative (absolute) geologic time and of relative geologic time, which is so richly manifested in the sequences of deposition and erosion recorded by Grand Canyon stratigraphy. In their research, Dodick and Orion (2003b) found that a respondent's skills in spatial-visual perception influences how he or she understands the temporal relationship among geological strata. This correlation between spatial and temporal perception has precedence in the research literature; in fact, it was first suggested by the philosopher Kant in the 18th century (Friedman, 1990). More recently, Friedman (1983, 1989, 1992) suggested that adolescents and adults represent conventional time systems (such as the days of the week) in a spatial fashion. This connection between spatial and temporal understanding has important implications for our work, as one of the goals of the exhibition is to help visitors integrate the horizontal timeline of the Trail of Time with stratigraphic time encoded vertically in the exposures of Grand Canyon.

Indeed, Dodick and Orion (2003a) suggest that a key element in building an understanding of geologic time is exposure to geologic structures in their natural settings, as it provides an opportunity to puzzle out the three-dimensional features of strata and their temporal relationships. Such an experience cannot be provided by a two-dimensional image on paper or a flat screen. Although Dodick and Orion's research was tested on high-school geology students, we posit that a similar dynamic takes place with Grand Canyon visitors. The Grand Canyon represents their "fieldwork" experience, and exposure to both the timeline Trail and its corresponding strata should allow them to build a better understanding of relative and quantitative geologic time.

It has also been suggested that kinesthetic means of learning reinforce spatial abilities (Gyllenhaal, 2006; Tretter et al., 2006), but this has not been extended to studies of temporal learning. These ideas can readily be tested at the Trail of Time. One important component of the Trail of Time project is an accompanying research study to investigate the development of the general public's understanding of "deep time", and the effectiveness of instructional strategies (e.g., analogies) to foster such understanding. The research study is characterizing visitor preconceptions related to time and change, and assessing the effectiveness of the timeline analogy as well as various ancillary materials in addressing misconceptions.

An offsite pilot test of the design of the "Million Year Trail" segment of the Trail of Time (Semken et al., 2007 and in prep.) has shown that respondents (mostly university students) were able to quickly learn the function of the logarithmically scaled timeline as they were asked to locate specific recent to geologically ancient dates along its length. When each of the meter markers was labeled with the appropriate time, respondents accurately navigated the test trail with no errors, even in the absence of additional signage to mark or describe the scale changes. The presence of the labeled meter markers alone was sufficient for respondents to grasp the periodicity of the time scale changes.

The Trail of Time project is an exciting venture into an extremely important area of geoscience teaching and learning. The design and research results will be applicable to many other types of informal geoscience education exhibits and programs, as well as many others that deal with scientific phenomena that involve vast scales of time, such as evolutionary biology or astronomy. While the project is still a number of months and years away from being fully implemented, the authors welcome feedback and comments and encourage readers to contact us directly.

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