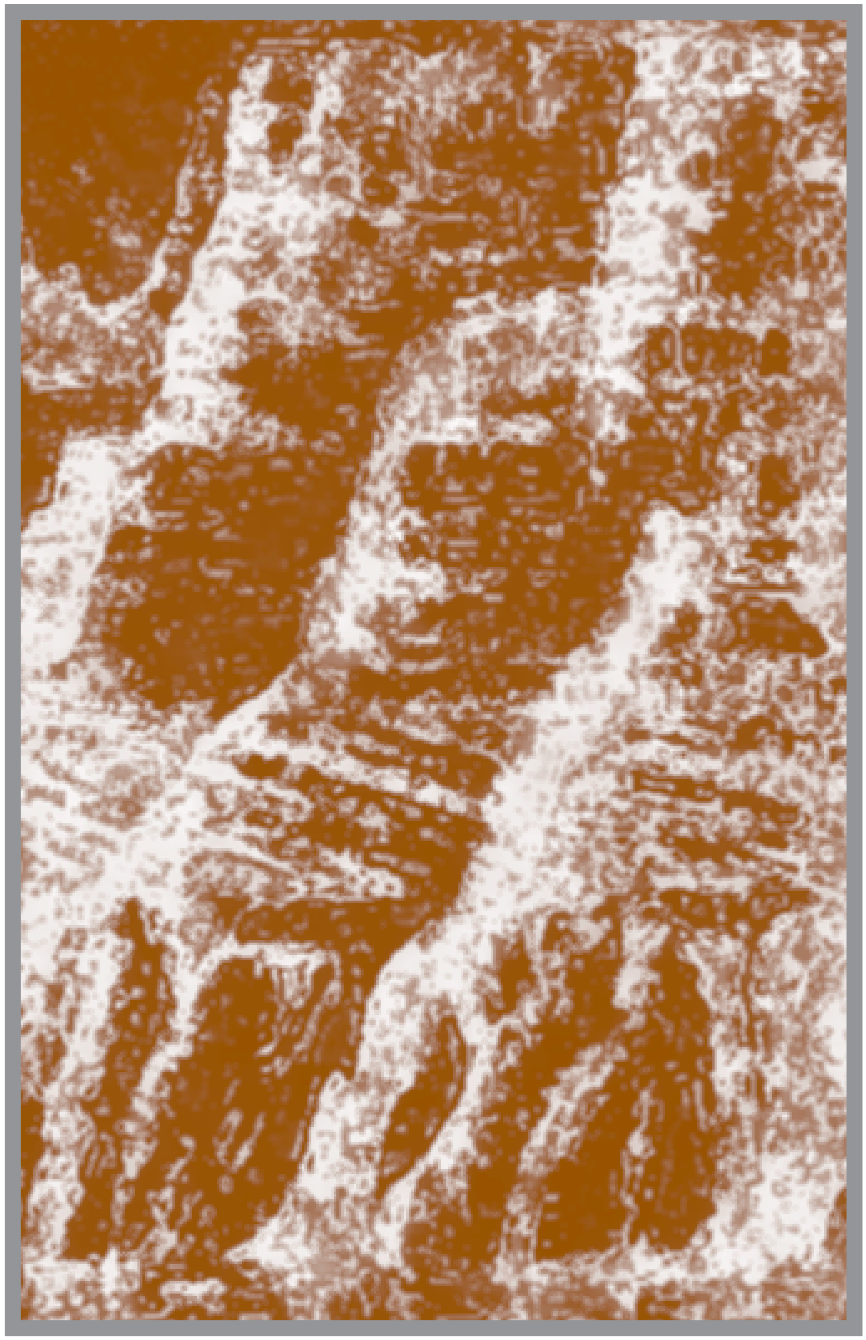
# Telling time at Grand Canyon National Park

By Allyson Mathis and Carl Bowman



With one of the clearest exposures of the rock record and a long, diverse geologic history, Grand Canyon is an ideal place to gain a sense of geologic or "deep" time. The oldest rocks exposed in the canyon are ancient, 1,840 million years old. Conversely, the canyon itself is geologically young, having been carved in the last 6 million years. Even younger deposits, including ice age fossils in caves, 1,000 year-old lava flows in the western canyon, and recently deposited debris flows, bring Grand Canyon's geologic record to the present.

Understanding the park's natural resources is undeniably intertwined with its geologic history; therefore, telling geologic time is an important part of the interpretive efforts at Grand Canyon National Park (Arizona). An appreciation of geologic time places geologic topics such as geomorphology, the origin and evolution of the Colorado River, stratigraphy, historical geology, and paleontology in context. Unfortunately, telling geologic time is a mystery to visitors and park staff without backgrounds in Earth science. Naturally a non-geoscientist may wonder, "How do you know that?" when a geologist or interpreter says "That rock formed 270 million years ago." To add to the confusion, both technical and popular literature report a wide variety of numeric ages for Grand Canyon rocks. For example, one publication may say that the Kaibab Formation is 270 million years old, while another says 255 million years old. The same inconsistencies arise for the other rock units in the park. At best, readers are left wondering which are the correct (or "best") ages and why. At worst, they may discount the scientific processes used to measure deep time.

When one's objective is simply to learn how old a rock layer is, sorting through the subdivisions of geologic periods, the scientific names of microscopic index fossils (diagnostic assemblages of past life), and the nuances of radiometric dating techniques is very confusing. Moreover, most non-geoscientists will not find a description of the Kaibab Formation as Leonardian or Roadian (stages) meaningful. However, they will be able to comprehend the numeric value of 270 million years (at least to the degree that geologic time is understandable). Therefore, numeric ages are essential when interpreters and resource managers communicate geology to the public and to one another. However, finding such numbers in the scientific literature is not easy. Unless researchers used absolute-dating techniques in a study, only the relative geologic age (i.e., period, epoch, or stage) of a rock unit is usually reported. Moreover, the scientific papers that do publish absolute age determinations are not always clear about the geologic significance of these dates.

Given the inconsistencies in reported numeric ages for Grand Canyon rocks and the difficulty in determining their ages, we reviewed the technical literature and consulted with researchers to compile the "best" ages of Grand Canyon rocks. By "best" we mean the most accurate and precise ages, given the parameters of geologic dating techniques and available information from the rock record. The primary audiences for this work were interpreters (including NPS rangers, commercial guides, authors, and publishers) and resource managers. The goal was to develop a single list of numeric ages that users could apply consistently, thereby facilitating comprehension of the geologic history and features of the Grand Canyon.

## Dating rocks

Two major categories of geologic dating techniques exist: relative dating and absolute age determinations. Relative dating determines the order in which a sequence of geologic events (e.g., volcanic eruptions, mountain building, sea-level rise, and deposition of sedimentary strata) occurred, but not how long ago the events happened. Absolute age determinations, such as radiometric age determinations, identify when, in years, specific events occurred. Depending on the availability of datable material (e.g., diagnostic minerals suitable for radiometric dating) and the presence of index fossils, investigators have used both techniques to discern the ages of rocks exposed in the Grand Canyon. Sedimentary rocks, which usually do not yield absolute ages, rely on relative dating, correlation, and the use of index fossils. Decaying radioactive isotopes in igneous and metamorphic rocks yield absolute ages.

One of our concerns with the large range ages published in scientific and popular texts is the potential to propagate outdated information and errors. The different ages are a result of improving knowledge, both in the accuracy and precision of geologic dating techniques, and in refinements to the geologic time scale. If interpreters and authors of general interest publications do not research primary scientific sources for their information, a superseded date from a widely distributed, popular publication may be erroneously cited again and again.

## The age of Grand Canyon rocks

Beginning with John Wesley Powell in the 1870s, geologists have recognized three main packages, or "sets," of rocks exposed in the Grand Canyon: (1) the crystalline rocks of the Inner Gorge, (2) the tilted rocks of the Grand Canyon Supergroup, and (3) the layered sedimentary rocks in the upper two-thirds of the canyon (fig. 1). As knowledge of Grand Canyon geology progressed, geologists began to identify individual layers of rocks; ultimately more than 100 formal stratigraphic names were applied to rock units in the Grand Canyon. Therefore, our project first required identifying the rock units for which numeric ages are important. We limited our project to the three overall sets of rocks and those rock formations or groups that interpreters and resource managers routinely discuss.

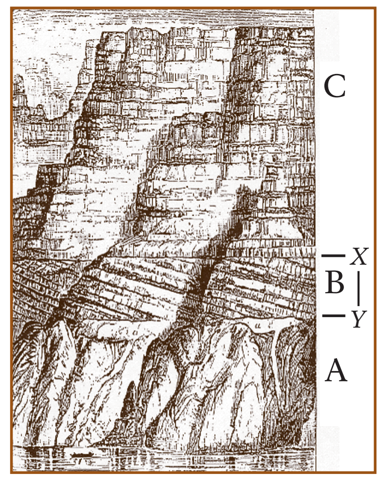


**Figure 1. Figure 79 in *Exploration of the Colorado River of the West and its Tributaries* (1875) by John Wesley Powell clearly shows that early geologists recognized the three main packages of rocks exposed in the Grand Canyon.**

In an effort to not confuse our users, we selected the term "set" to refer to Powell's three main packages of rocks, because this term is not part of the formal stratigraphic hierarchy such as "group," "series," or "complex." The three sets of rocks are categorized based on stratigraphic position, age, physical characteristics, and overall geologic history (table 1, page 82). The "Vishnu Basement Rocks" (of undetermined thickness) consist of the ancient igneous and metamorphic rocks exposed in the Inner Gorge. The "Grand Canyon Supergroup Rocks" (12,000 feet [3,600 m] thick) are late Precambrian sedimentary and volcanic rocks predominantly deposited in rifted basins. The "Layered Paleozoic Rocks" (3,000–4,000 feet [900–1,200 m] thick) include the flat-lying sedimentary rocks in the "stair-step" canyon walls (figs. 2 and 3, pages 80–81).

Within these sets, we assigned numeric ages for 17 units at the group or formation level, using radiometric dates where available (table 1). Our goal was to be as accurate as possible in assigning numeric ages. Only where the science allowed did we round numbers for easier interpretive use and better retention by the public. These numeric ages are an important translation for park managers and the public; they also promote consistency and utility in interpretive and resource-management communications.

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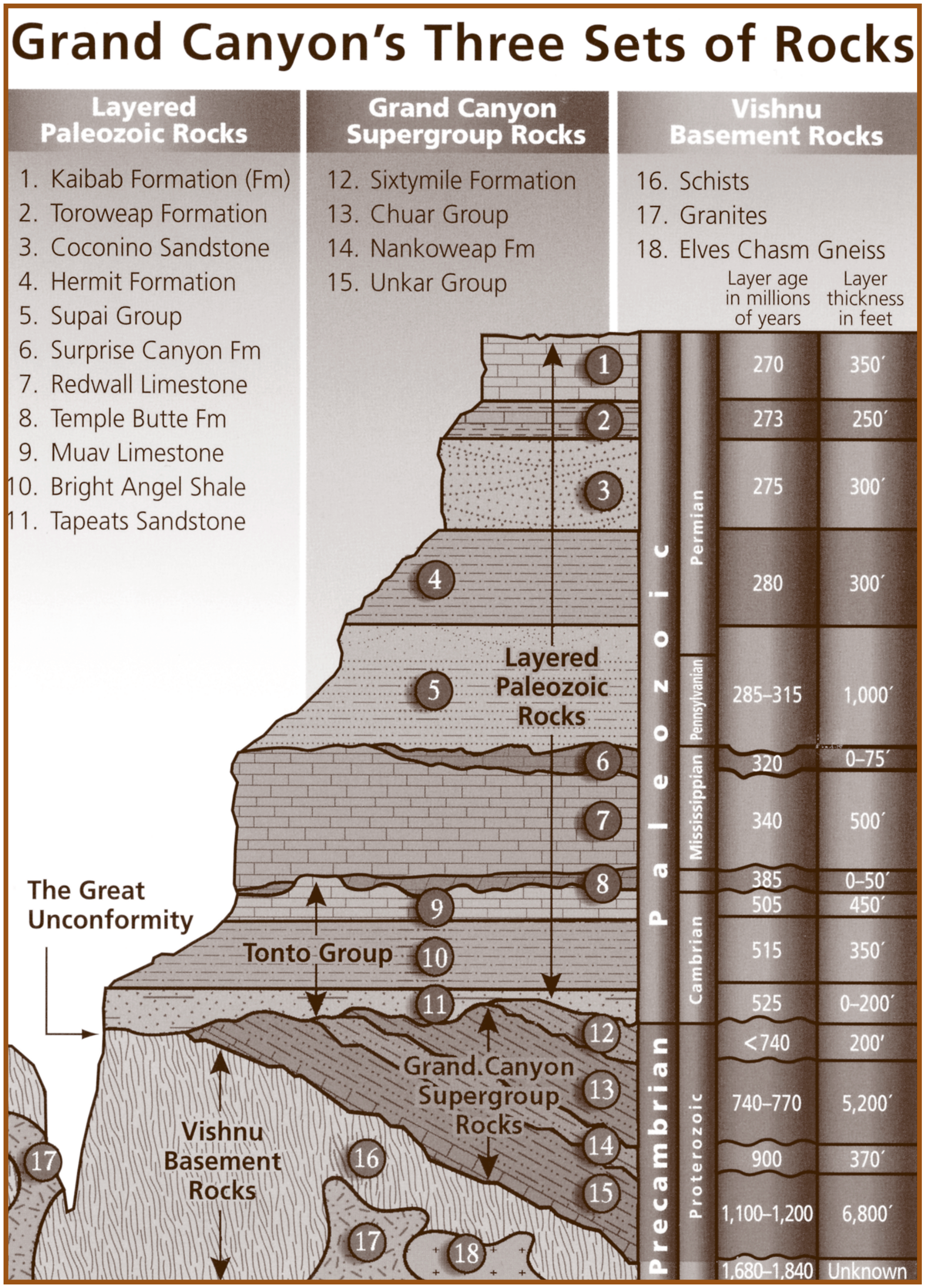
## Vishnu Basement Rocks

We established the informal name Vishnu Basement Rocks for all of the ancient crystalline rocks at the bottom of the Grand Canyon because no formal nomenclature encompasses all the metamorphic units and individual igneous plutons exposed there. We chose "Vishnu" because the public is familiar with the Vishnu Schist and "basement" to indicate the type of rock assemblage and its position.

The many reliable radiometric age determinations of the igneous and metamorphic Vishnu Basement Rocks (e.g., Ilg et al. 1996; Hawkins et al. 1996; Karlstrom et al. 2003) facilitated our determination of numeric ages for this set. The challenge was to interpret the geologic significance of the dates in a meaningful context for interpreters and resource managers. We differentiated Grand Canyon's oldest rock unit, the Elves Chasm Pluton (1,840 million years ago), from the rest of the Vishnu Basement Rocks. The Elves Chasm is significantly older, at least 90 million years, than any other basement rock. It formed before the main tectonic collisions that produced most of the other rocks comprising the Vishnu Basement Rocks (1,680–1,750 million years ago). We also chose to exclude a few younger plutons, which formed about 1,400 million years ago, from the overall age of the Vishnu Basement Rocks. These rocks postdate the main tectonic events that formed this set and, though interesting, are a detail better left to the advanced study of Grand Canyon geology.

## Grand Canyon Supergroup Rocks

Grand Canyon Supergroup Rocks are primarily sedimentary. However, radiometric age determinations of the Cardenas Basalt, ash beds, and other datable material within the sedimentary rocks provide age constraints for this set. We included some dates from paleomagnetic stud-



ies, which use the natural remnant magnetization in Earth materials, to further define the time span. The Supergroup rocks predate the Cambrian Period, when hard-shelled organisms first appeared in the fossil record, so they have few identifiable index fossils. Our dates are bracketed by the ages of the basal Unkar Group at 1,100–1,200 million years ago (Arizona Geological Survey, M. Timmons, personal communications, 2003–2005) and the Chuar Group at 740–770 million years ago (Dehler et al. 2005). No datable material has been found in the uppermost Sixtymile Formation (see table 1). The Supergroup is the focus of active geologic investigation, so these ages may change as new information becomes available.

## Layered Paleozoic Rocks

Assigning numeric ages for units of the Layered Paleozoic Rocks was the most difficult. Because no single stratigraphic name exists for this set, Layered Paleozoic Rocks is also an informal term; nevertheless, their rock type, age, and overall geologic setting naturally package them together. No reliable radiometric dates exist for these sedimentary rocks, so their ages are constrained by index fossils. Units with richer fossil records have more precise age constraints. After analyzing a unit's fossil assemblages, researchers identify the geologic age (Beus and Morales 2003) by correlation to chronostratigraphic charts. All geologists use the same basic divisions of geologic time (e.g., eras and periods). The *International Stratigraphic Chart* (Grandstein and Ogg 2004; International Commission on Stratigraphy 2005) is the most accurate and up-to-date time scale available for worldwide correlation of rock units. We used it as our basis for determining the numeric ages for rocks in Grand Canyon National Park. However, investigators have used many local or regional scales, such as the *North American Chronostratigraphic Scale*, for finer subdivisions. These other scales work well for describing regional geology but can be difficult to correlate worldwide. The relationship between the *North American Chronostratigraphic Scale* and the *International Stratigraphic Chart* is not straightforward. Hence, we consulted Dr. Ronald Blakey, a stratigrapher at Northern Arizona University, to ensure that we had developed a set of reasonable dates for the Layered Paleozoic Rocks.

The other challenge of determining the age of the Layered Paleozoic Rocks was identifying the best single number to represent the age of each unit. Sedimentary rocks are usually deposited over long periods of time, and some units exposed in Grand Canyon contain significant gaps in the rock record, called unconformities. Furthermore, many formations, in particular the Tonto Group, record marine transgressions as sea level rose, making the unit older in the west than in the east. Because most developed areas of Grand Canyon National Park are in the eastern canyon, we targeted our compilation on the age of rocks there.

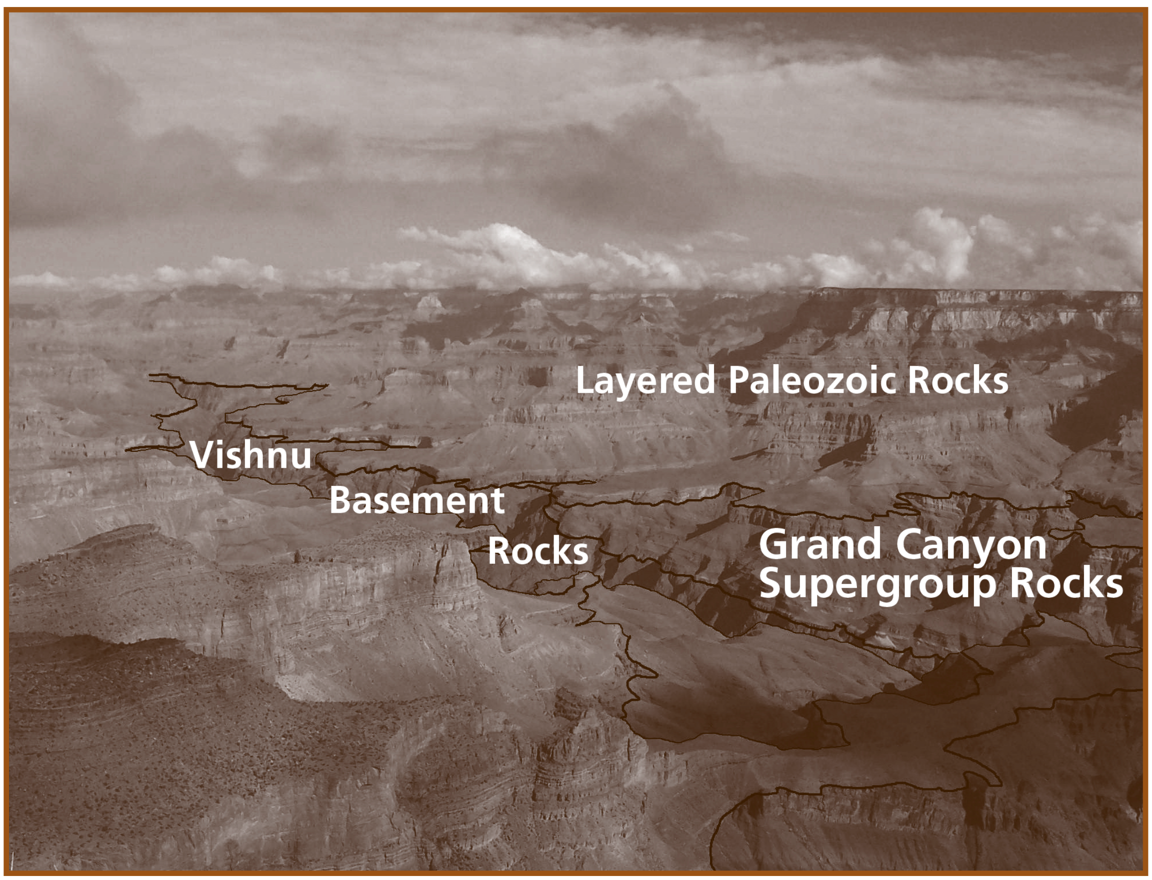



**Figure 2 (facing page). This stratigraphic column, developed for *Grand Canyon Yardstick of Geologic Time* (Mathis 2006), shows the three sets of rocks. Descriptions of the canyon's geologic history often focus on individual rock layers, particularly the easily recognized, horizontal sedimentary rock layers, and less on the overall stories of the three sets of rocks exposed in the canyon. Truer understanding of the canyon's history comes when individual rock units are placed in the context of the three sets.** COPYRIGHT GRAND CANYON ASSOCIATION

**Figure 3. The view of the Grand Canyon from Moran Point shows the Vishnu Basement Rocks in the Inner Gorge, the tilted Grand Canyon Supergroup Rocks, and the Layered Paleozoic Rocks.** NPS/CARL BOWMAN

**Table 1. Sets of rocks at Grand Canyon National Park**

| Set | Formation name | | Numeric age[1] (millions of years ago) | Geologic age | Rock type(s) | Layering | Geologic setting |
|---|---|---|---|---|---|---|---|
| Layered Paleozoic Rocks | Kaibab Formation | | 270 | Permian | Sedimentary | Horizontal | Coastal plains form alternately above and below sea level |
| | Toroweap Formation | | 273 | | | | |
| | Coconino Sandstone | | 275 | | | | |
| | Hermit Formation | | 280 | | | | |
| | Supai Group | Esplanade Sandstone | 285–315 | | | | |
| | | Wescogame Formation | | Pennsylvanian | | | |
| | | Manakacha Formation | | | | | |
| | | Watahomigi Formation | | | | | |
| | Surprise Canyon Formation | | 320 | Mississippian | | | |
| | Redwall Limestone | | 340 | | | | |
| | Temple Butte Formation | | 385 | Devonian | | | |
| | Tonto Group | Muav Limestone | 505 | Cambrian | | | |
| | | Bright Angel Shale | 515 | | | | |
| | | Tapeats Sandstone | 525 | | | | |
| Grand Canyon Supergroup Rocks | Sixtymile Formation | | 740 | Precambrian | Sedimentary with some igneous | Tilted | Basins open as seaway develops |
| | Chuar Group | | 740–770 | | | | |
| | Nankoweap Formation | | 900 | | | | |
| | Unkar Group | | 1,100–1,200 | | | | |
| Vishnu Basement Rocks | Vishnu, Brahma, and Rama schists; most plutonic rocks | | 1,680–1,750 (~1700) | | Metamorphic and igneous | Vertical | Island chains collide with the continent |
| | Elves Chasm Pluton | | 1,840 | | | | |

[1]International Stratigraphic Commission (2005).

## Results and distribution

We completed our original compilation of Grand Canyon rocks in 2003. Because of refinements in the geologic time scale and new findings by researchers, we revised it in 2004. Further revisions may be necessary as knowledge of Grand Canyon geology improves, new or improved absolute dating techniques are developed, or the geologic time scale is modified. Given the current knowledge of Grand Canyon geology, table 1 compiles our best numeric ages of its rocks.

Originally, we only distributed our age compilation to staffs at the Grand Canyon Association (GCA) and Grand Canyon National Park. Both now use the numeric ages in their interpretive programs, publications, exhibits, and resource management reports (fig. 4). We later wrote a series of articles published in *Nature Notes* and *Boatman's Quarterly Review*. These articles,

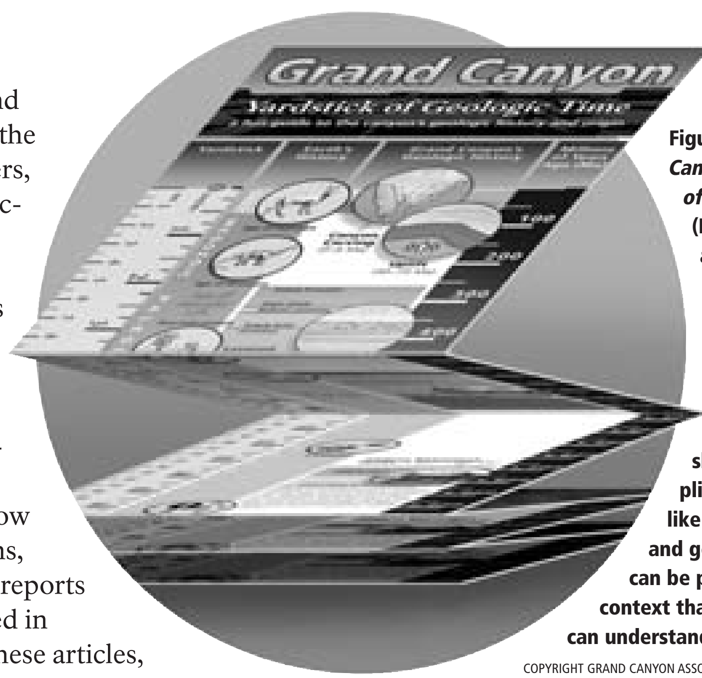



**Figure 4. *Grand Canyon Yardstick of Geologic Time* (Mathis 2006) is an interpretive publication about geologic time and the ages of Grand Canyon rocks. It shows how complicated subjects like geochronology and geologic history can be placed into a context that park visitors can understand.**

which targeted lay audiences and Colorado River guides, explained geologic dating techniques and summarized the ages of Grand Canyon rocks. These publications further encouraged consistency among park cooperators who interpret and otherwise communicate the ages of Grand Canyon rocks.

The interpretive articles and age charts are available to an even wider audience through the Tour of Park Geology Web site maintained by the NPS Geologic Resources Division (http://www2.nature. nps.gov/geology/parks/grca/age/). The U.S. Geological Survey also used our compilation in their Geology of National Parks Web site at http://3dparks.wr.usgs.gov/ (accessed 13 December 2006).

## Conclusions

From literature searches, consultations with geologists, and interpretations of scientific data, we compiled the numeric ages of rocks exposed in Grand Canyon National Park. Our age compilation provides information about the age of Grand Canyon rocks in a form meaningful to interpreters, park managers, and visitors. The primary outcome of this project is that the ages given for Grand Canyon rocks are more consistent in interpretive media, park documents, and popular GCA publications. While the compilation is our primary product, the interpretive publications based on this work provide additional information about how geologists tell time and why these dates are important. With this broader perspective, the age of Grand Canyon rocks becomes more meaningful. Furthermore, providing a consistent set of reliable ages adds to the credibility of geologic interpretation.

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This project is a good example of collaboration among scientists, resource managers, and interpreters. Interpreters had a significant need for consistent, reliable ages for Grand Canyon rocks, which this project filled; they also gained a better understanding of geologic dating techniques. With increased knowledge, interpreters may be able to facilitate greater comprehension of the science behind their geologic presentations. Additionally, this compilation and accompanying background information about dating methods can help interpreters address the socio-political controversy regarding deep time and evolution. Resource managers benefit by having an internally consistent and scientifically credible time scale to apply to internal and external geologic and paleontological work. Finally, working directly with researchers has fostered communication and credibility among park interpreters, resource managers, and the academic community.

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