Nature Notes

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What's in a Number?

Numeric Ages for Rocks Exposed within Grand Canyon Part 2

By Allyson Mathis and Carl Bowman, National Park Service, Grand Canyon

Grand Canyon is one of the best places in the world to gain a sense of geologic, or "deep," time, because the canyon exposes a great swath of geologic history. Rocks exposed in Grand Canyon are truly ancient, ranging from 1,840 million years old (m.y.), or 1.84 billion years old (b.y.), to 270 m.y. The Grand Canyon landscape is geologically young, being carved within just the last six million years. Additionally, there are younger geologic deposits in Grand Canyon, such as the Ice Age fossils found in caves, a 1,000-year-old lava flow in the western canyon, and even the debris-flow deposits that continue to form each year.

Yet, it is the canyon's rock walls that allow people to develop their greatest perspective on geologic time, because of these rocks' immense age and their fossil record and because these rocks formed in environments far different than those found in northern Arizona today. With a rock record that spans more than 1,500 million years, Grand Canyon is truly a panoramic view into the geologic past.

In our previous article (Mathis and Bowman, 2005), we summarized how geologists determine the age of rocks in general, and introduced how absolute and relative age techniques are applied to rocks exposed in Grand Canyon. This article elaborates on how the numeric ages of Grand Canyon rocks were determined and describes Grand Canyon rocks as belonging to three "sets," or packages of rocks, each with unique geologic histories.

A Review: Absolute and Relative Age Determinations

Geologists use both absolute and relative age determinations to identify the age of rocks and other geologic features. Absolute ages are numeric and identify the time in years when specific geologic events, such as the formation of a rock, happened. Radiometric dating, which takes advantage of the decay of radioisotopes naturally present in rocks, is the most commonly used type of absolute age determination in geology.

Relative dating determines the order in which a sequence of past events occurred, yet cannot determine in years exactly when the geologic events happened. Both relative and absolute age determinations are important in different geologic situations and have been used together to discern the ages of individual rock units exposed in Grand Canyon (Table 1). Our previous article provides more details on geologic dating techniques.

Three Sets of Rocks

Geologists, beginning with John Wesley Powell, have long recognized that there are three main packages or "sets" of rocks exposed in Grand Canyon (Figure 1): the crystalline rocks of the Inner Gorge, the tilted rocks of the Grand Canyon Supergroup, and the layered sedimentary rocks in the upper two-thirds of the canyon. As knowledge of Grand Canyon geology progressed, individual rock units, or formations, were identified, and ultimately more than 100 formal stratigraphic names were applied to mappable rock units found within the canyon.

Interpretation of the canyon's geology often focuses more on individual rock layers, particularly the flat-lying sedimentary rock layers easily identified from the rim, and less on the overall

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Set	Formation		Chronostratigraphic Age	Numeric Age [Geologic Time Scale 2004 (ICS)]	Notes
Layered Paleozoic Rocks	Kaibab Formation		Early Middle Permian	270 m.y.	
	Toroweap Formation		Late Early Permian	273 m.y.	
	Coconino Sandstone		Early Permian	275 m.y.	
	Hermit Formation		Early Permian	280 m.y.	
	Supai Group	Esplanade Sandstone	Early Permian	315–285 m.y.	Range in age for the Supai Group reflects the long period of deposition for this group and significant unconformities within the group.
		Wescogame Fm	Late Pennsylvanian		
		Manakacha Fm	Early Pennsylvanian		
		Watahomigi Fm	Early Pennsylvanian		
	Surprise Canyon Formation		Late Mississippian	320 m.y.	
	Redwall Limestone		Late Early – Middle Miss.	340 m.y.	
	Temple Butte Formation		Middle – Late Devonian	385 m.y.	
	Tonto Group	Muav Limestone	Middle Cambrian	505 m.y.	Deposition of the Tonto Group began earlier in the western Grand Canyon.
		Bright Angel Shale	Early – Middle Cambrian	515 m.y.	
		Tapeats Sandstone	Early Cambrian	525 m.y.	
Grand Canyon Supergroup Rocks	Sixtymile Formation		Neoproterozoic	≤ 740 m.y.	Most numeric ages for the Supergroup were obtained via radiometric dates on volcanic ash beds, lava flows and other datable rocks within the sequence. There are no numeric ages available for the Sixtymile Fm., but it is inferred not to be much younger than the Chuar Group, although Karlstrom thinks that the Sixtymile Fm. may be as young as 725 m.y. based on correlation to the "Snowball Earth." Because this proposed age is not as substantiated as the other numeric ages in this compilation, we left the upper boundary for Supergroup at 740 m.y., which is close to the youngest reliable date from the Chuar Group
	Chuar Group		Neoproterozoic	770–740 m.y.	
	Nankoweap Formation		Neoproterozoic	900 m.y.	
	Unkar Group		Mesoproterozoic	1200–1100 m.y.	
Vishnu Basement Rocks	Vishnu, Brahma, and Rama Schists; most plutonic rocks		Paleoproterozoic	1750–1680 m.y. (~1700 m.y.)	Deposition of the sedimentary and volcanic precursors to the metamorphic rocks occurred predominantly 1750–1730 m.y. 1700 m.y. is the time of peak metamorphism and can be used if a single number for the crystalline basement rocks is needed. Some plutonic (igneous) rocks (e.g., the Quartermaster Pluton) in the Lower Granite Gorge are significantly younger at ~ 1400 m.y.
	Elves Chasm Pluton		Paleoproterozoic	1840 m.y.	U-Pb dating on zircons for the crystallization age of the pluton (1840 ± 1 m.y.). The Elves Chasm Pluton is the "basement for the basement" and is substantially older than other dated rocks in the Inner Gorge.

Table 1: Numeric ages for rocks exposed in Grand Canyon National Park

stories of the three sets of rocks exposed in the canyon. The individual rock layers are like snapshots of the geologic past. Using the three sets places these snapshots into an album and gives an overall context to the story of each rock unit. For example, the Redwall Limestone was deposited in a shallow ocean approximately 340 m.y., yet it is only one of many sedimentary rock layers deposited in, along, or near a coastline that moved across what is now northern Arizona for about 250 million years, when this area was free of major geologic upheavals. Focusing on only the flat-lying sedimentary rocks of the upper part of the canyon overlooks the rich and dramatic geologic stories of the other rocks exposed deeper within Grand Canyon. Using the three sets of rocks can make this whole story easier to tell.

We use the informal term "sets" to indicate the three main packages of rocks exposed within the canyon. ("Set" is used because it is not a part of formal stratigraphic hierarchy like group, series, or complex.) The three sets of rocks are differentiated on the basis of not only stratigraphic position, but also age, rock type, and overall geologic setting in which they formed (Table 2). The Vishnu Basement Rocks consist of all the crystalline rocks exposed near the bottom of Grand Canyon. The Grand Canyon Supergroup Rocks include sedimentary and volcanic rocks deposited in coastal basins and were tilted as joined continents separated. The Layered Paleozoic Rocks include the 3,000–4,000 feet of flat-lying sedimentary rocks that make up the "stairstep" canyon (Figure 2).

Vishnu Basement Rocks: The Making of the Continent

The Vishnu Basement Rocks include the metamorphic (recrystallized due to heat and pressure) and igneous ("fire-born") rocks exposed within what Powell named the "Granite Gorge." This rock assemblage records the building of North America by collisions, in this case, of volcanic island chains with the continental landmass. These collisions generated intense heat and pressure deep within the crust yielding metamorphic and igneous rocks while mountain ranges formed at the surface. Like the basement of a house, basement rocks are the foundation of continents. No older rocks exist beneath the Vishnu Basement Rocks.

No single formal stratigraphic term refers to all igneous and metamorphic rocks exposed in Grand Canyon. Therefore, we use the informal term "Vishnu Basement Rocks" to refer to these rocks: "Vishnu" because the public is familiar with the Vishnu Schist, and "basement" to indicate the type of rock assemblage and to imply that these rocks are exposed at the bottom of Grand Canyon. The names "Vishnu Schist" and "Zoroaster Granite" are well known to the general public, but they are only two of at least 25 named rock units found in the Inner Gorge. Therefore, these names cannot be used to refer to the full suite of diverse crystalline rocks exposed in Grand Canyon. Even the formal term "Granite Gorge Metamorphic Suite" (Ilg et al, 1996) only includes the Vishnu, Brahma, and Rama Schists, and excludes all igneous rocks found in the basement complex. And unlike the metamorphic rocks, no single term includes all the igneous rocks ("plutons"). Each pluton is a discrete igneous intrusion with its own specific crystallization history and its own name. Referring to all of the canyon's plutonic rocks as the "Zoroaster Granite" incorrectly oversimplifies this complex assemblage of igneous rocks.

Absolute age determinations constrain the age of the Vishnu Basement Rocks. For igneous rocks, radiometric age determinations reveal the time of crystallization. For metamorphic rocks, radiometric dates can determine the time of metamorphism, or in specific cases, can even reveal the time of original crystallization of an igneous rock that was later metamorphosed.

Detailed geologic reconstruction and radiometric age determinations have unraveled the geologic history of the Vishnu Basement Rocks (Karlstrom et al, 2003). The oldest rock in Grand Canyon is the Elves Chasm Gneiss, only found near Elves Chasm. It formed 1,840 m.y. and is 90 m.y. older than any other rock found in the canyon. Although the specific origin of the Elves Chasm Gneiss is unclear, it may be a fragment of older continental crust or may be part of the "basement for the basement." Most of the Vishnu Basement Rocks formed between 1,750 and 1,680 m.y. They record a complex geologic history of volcanic island chains near a continent between 1,750 and 1,730 m.y, in a region like the East Indian island chains adjacent to Asia today. In the American Southwest, the ancient islands began colliding with each other about 1,740 m.y., with peak metamorphism and igneous intrusion occurring 1,700 to 1,680 m.y. when the island chains themselves collided with the continent. Each of the three schists formed from different rock types. The Vishnu Schist formed from metamorphosed sedimentary rocks, and the Brahma and Rama Schists are metamorphosed volcanic rocks. The different igneous plutons likewise have different geologic origins. Some are crystallized magma chambers from volcanic islands, and others formed when the islands crashed into the continent.

Grand Canyon Supergroup Rocks: The Rifting of Continents

The Grand Canyon Supergroup Rocks consist of several named groups and formations: the Unkar Group, Nankoweap Formation, Chuar Group, and Sixtymile Formation. These units are made up of mostly sedimentary rocks with only a few interlayered igneous rocks, such as the Cardenas Basalt. These rocks were deposited in active valleys formed by faulting, or rifting, somewhat like the modern basins of the Basin and Range in Nevada. But the Supergroup basins were flooded by marine waters. At least some of these valleys, such as the ones in which the rocks of the Chuar Group were deposited, formed as an ancient supercontinent called Rodinia separated, and a new ocean basin opened. The 10-degree dip of these rocks resulted from tilting and faulting that occurred during and after deposition of these sedimentary rocks. Active faulting during deposition allowed great thicknesses of Supergroup sediments to accumulate. The cumulative thickness of the entire Grand Canyon Supergroup is 12,000 feet. The Supergroup rocks are visible today in places near the Colorado River, especially below Desert

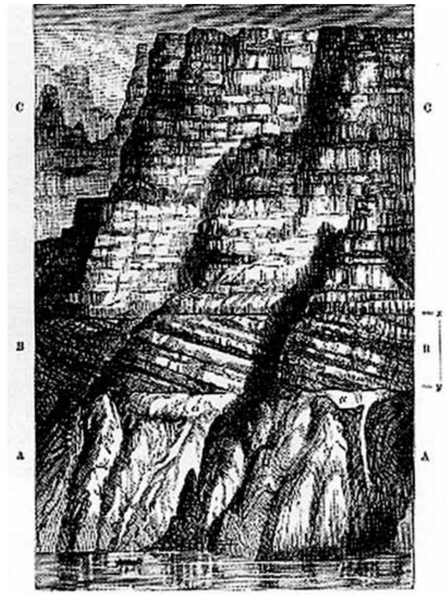

Figure 1: Figure 79 from John Wesley Powell's 1975 Exploration of the Colorado River of the West and its Tributaries. *Although this illustration does not correctly portray the contacts between the three sets of rocks, it clearly shows that Powell recognized the three main packages of rocks exposed in Grand Canyon.*

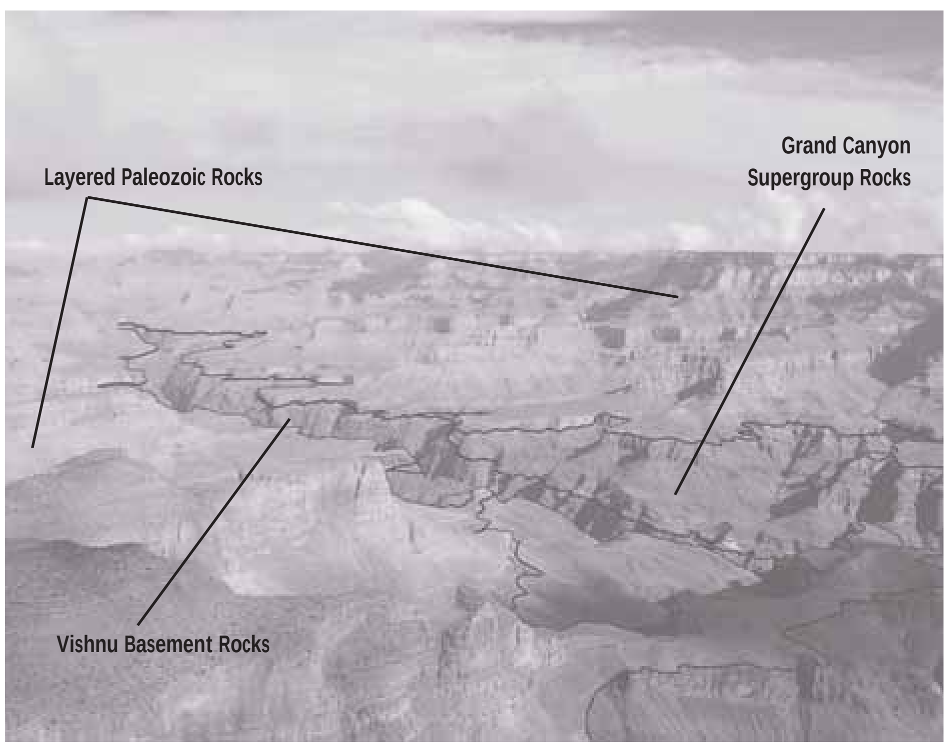

Figure 2: Grand Canyon from Moran Point showing the Vishnu Basement Rocks in the Inner Gorge, the tilted Grand Canyon Supergroup Rocks and the Layered Paleozoic Rocks.

Set	Geologic Age	Numeric Age	Rock type(s)	Geologic Setting	Layering
Layered Paleozoic Rocks	Paleozoic	270–525 m.y.	Sedimentary	Coastal plains alternately above and below sea level	Horizontal
Grand Canyon Supergroup Rocks	Precambrian	740–1200 m.y.	Sedimentary with some igneous	Basins pulled open as ocean basins develop	Tilted
Vishnu Basement Rocks	Precambrian	1680–1840 m.y.	Metamorphic and igneous	Island chain collisions with the continent	Vertical

Table 2: Grand Canyon's three sets of rocks

View, where down-faulted blocks protected them from subsequent erosion prior to the deposition of the Layered Paleozoic Rocks.

Normally, sedimentary rock units are assigned numeric ages based on the presence of index fossils, worldwide correlation, and the geologic time scale (see Mathis and Bowman, 2005). Unfortunately, since the Grand Canyon Supergroup Rocks are so ancient, they formed before life diversified and developed hard parts. There are few, if any, index fossils identified in Precambrian rocks. The few fossils that have been found in Supergroup rocks suggest these rocks' great antiquity, but the fossils cannot be used to pinpoint the age of the Supergroup. However, the igneous Cardenas Basalt and a few volcanic ash beds or zircon grains in sedimentary rocks have been successfully dated radiometrically. They bracket the ages of the Unkar and Chuar groups at approximately 1,200–1,100 m.y. and 770–740 m.y. respectively (Timmons 2005 – 2003, personal communication). The age of base of the Unkar Group was recently estimated, based on a new age determination (Timmons et al, 2005) of zircon grains found near the base of the Unkar Group, to be closer to 1,200 m.y. in age rather than the previously reported 1,250 m.y. This is an area of active research and uncertainties remain for the age of these hard-to-date rocks.

The Nankoweap Formation was tentatively dated at 900 m.y. using paleomagnetism, which measures the natural magnetism preserved in rocks from their time of formation and utilizes worldwide correlation to infer geologic age (Timmons 2005 – 2003, personal communication). These absolute age determinations provide important age constraints on the Grand Canyon Supergroup, yet our knowledge of these rocks' history is incomplete. The Sixtymile Formation has not been dated, and, in fact, may not contain any datable material. Its age may remain only as inferred as younger than 740 m.y. (but how much younger is still unclear).

Layered Paleozoic Rocks: The Quiet Edge of a Continent

As with the Vishnu Basement Rocks, no single term delineates all the flat-lying sedimentary rocks of Paleozoic age that are exposed in the cliff-and-slope pattern of the upper canyon walls. Although each geologic formation in the Layered Paleozoic Rocks records its individual depositional environment, together these rock layers also form a comprehensive set based on rock type, age, and overall geologic setting. For example, the Coconino Sandstone reveals only an ancient coastal sand dune field, yet all the flat-lying sedimentary rocks deposited during the Paleozoic Era reveal a quiet edge of North America. And although each individual rock layer of what we call the "Layered Paleozoic Rocks" is more easily identifiable to most canyon visitors than the individual formations within the other two sets, it is still important to place these geologic snapshots into the context of their set or album.

Determining numeric ages for the Layered Paleozoic Rocks was more difficult than that of the other two sets because no reliable absolute age determinations exist for these sedimentary rocks. However, many of these rock units, particularly marine units like the Kaibab Formation, contain abundant fossils from the Paleozoic Era. This rich fossil record, including many microscopic index fossils, allows worldwide correlation using the Geologic Time Scale (see Mathis and Bowman, 2005) to determine geologic ages (Beus and Morales, eds., 2003), such as the late Early to Middle Mississippian age of the Redwall Limestone. Given that the boundary between the Early and Middle Mississippian is at 345 m.y. (www.stratigraphy.org/chus.pdf), and that more of the Redwall was deposited in the Middle Mississippian than the early part of the period, it is easy to estimate that the Redwall Limestone was deposited approximately 340 m.y.

Of course, a single, inferred numeric age for sedimentary rocks is imperfect and cannot be precise. It obscures the reality that most sedimentary rock units were deposited over long periods of geologic time. Still, the numeric ages are valuable as a way to communicate the age of rocks to people who are not familiar with the Geologic Time Scale and the relative age of geologic periods like Mississippian and Pennsylvanian. Our compilation of numeric ages for each rock unit of the Layered Paleozoic Rocks (Table 1) is based on the geologic ages reported in the scientific literature, consultation with geologists who work on these rocks, and the Geologic Time Scale 2004. In short, it provides a single, reasonable, and standardized age to use for each layer.

Deposition of sediments was not continuous in the Grand Canyon region during the Paleozoic (between 525 and 270 m.y.), leaving significant gaps in age between some adjacent rock layers. These gaps in the geologic record, produced by erosion or nondeposition of sediment, are known as "unconformities." Unconformities exist not only between the three sets of rocks, but also within individual sets like the Layered Paleozoic Rocks. For example, a large unconformity exists between the 505 m.y. Muav Limestone and the overlying 385 m.y. Temple Butte Formation.

Summary

Since each of Grand Canyon's three sets of rocks is unique, different dating techniques were used to determine the age of the rocks in each set. Radiometric dating techniques revealed the absolute age of the igneous and metamorphic rocks of the Vishnu Basement Rocks and also provided dates on volcanic ash beds and other datable units in the mostly sedimentary Grand Canyon Supergroup. Relative dating, index fossils, and geologic correlation were used to determine the geologic age of the Layered Paleozoic Rocks, and numeric ages were then inferred.

A wide variety of numeric ages for Grand Canyon rocks, particularly for the sedimentary rocks which usually cannot be absolutely dated, exist in both the technical and popular literature. When someone's objective is really just to learn how long ago these rocks formed, it is very confusing to sort through subdivisions of geologic periods, the scientific names of microscopic index fossils and the nuances of radiometric dating techniques. Table 1 is a compilation of what we believe to be the best numeric ages of Grand Canyon rocks given the current knowledge of Grand Canyon geology and the geologic time scale. These numeric ages may need to be revised as knowledge of Grand Canyon improves, new or improved absolute-dating techniques are developed and/or the geologic time scale is modified. Although the ages in the chart were "set by stones," it is important to remember that, like all scientific findings, they are not "set in stone." Regardless of whatever revisions to the ages of Grand Canyon rocks occur with further scientific inquiry, most changes will only be on the order of a few million years, a very short period geologically. Grand Canyon will remain a great window into the deep history of our planet.

References

Beus, Stanley S., and Michael Morales, eds. 2003. *Grand Canyon Geology*, 2nd ed. New York: Oxford University Press.

Blakey, Ronald. 2004. Personal communication.

Ilg, Bradley R.; Karl E. Karlstrom; David P. Hawkins; and Michael L. Williams. 1996. Tectonic evolution of Paleoproterozoic rocks in the Grand Canyon: Insights into middle-crustal process. *Geological Society of America Bulletin*, v. 108, pp. 1149–1166.

International Commission on Stratigraphy. 2004. Geologic Time Scale 2004. New York: Cambridge University Press and www.stratigraphy.org/scale04.pdf.

International Commission on Stratigraphy. 2004. International stratigraphic chart. www.stratigraphy.org/chus.pdf.

Karlstrom, K. E.; B. R. Ilg; M. L. Williams; D. P. Hawkins; S. A. Bowring; and S. J. Seaman. 2003. Paleoproterozoic rocks of the Granite Gorges, in *Grand Canyon Geology*, 2nd ed., ed. by Stanley Beus and Michael Morales. New York: Oxford University Press, pp. 9–38.

Karlstrom, Karl. 2004. Personal communication.

Mathis, Allyson, and Carl Bowman. 2005. What's in a number? Numeric ages for rocks exposed within Grand Canyon. *Nature Notes*, v. 21, n. 1, pp. 1–4.

Powell, J.W. 1875. *Exploration of the Colorado River of the West and its tributaries. Explored in 1869, 1870, 1871, and 1872, under the direction of the Secretary of the Smithsonian Institution.* Washington, D.C.: U.S. Government Printing Office.

Timmons, J.M.; K. Fletcher; K. Karlstrom; M. Heizler; G. Gehrels; S. Bowring; and L. Crossey. 2005. The Mesoproterozoic Grand Canyon Unkar Group: A detailed record of intracratonic basin formation and deformation during Grenville-age orogenesis. *Geological Society of America Annual Abstracts with Programs*, Paper No. 224-8, Abstract ID 95694, v. 37, n. 7, p. 494.

Timmons, Michael, 2005 – 2003, personal communication.

NPS photograph

Using Travertine Deposits to Determine the Age of Grand Canyon

By Lon Abbott

Grand Canyon is both a natural wonder and an unrivalled repository of geologic information. Etched into its rock walls are the stories of almost two *billion* years of Earth history, revealed in exquisitely vivid detail. Through study of the canyon's rocks, we can chronicle the growth and modification of the early North American continent, track the rise and fall of numerous seas, trace dramatic shifts in climate from the verdantly tropical to the desiccatingly arid, and reconstruct the area's ancient geography down to the level of individual islets that dotted a shallow sea almost 550 million years ago.

Considering the clarity of the window into the past that the canyon provides, it is surprising and somewhat ironic that one of the fuzziest parts of the entire story is one of the most recent and dramatic events: the carving of Grand Canyon itself. Geologists have been able to construct the broad outline of the carving story, but many important details are still far from clear. The canyon as we know it was born about six million years ago, but the exact process that triggered its birth and subsequent growth, and how fast that growth occurred, remain uncertain. The erosion processes that carved the canyon swept away many of the rock layers that, if preserved, would provide the clues geologists need to determine how and how fast the canyon was cut. Only a few fragmental clues remain. Geologists are attempting to harness every new technological innovation that will allow them to analyze those clues in new and different ways so as to squeeze from them a bit more of the story.

One important rock clue that has not been eroded away is the abundant travertine that was deposited in the canyon by springs over the last few million years. The spectacular waterfalls of Havasu Creek are the best known of these travertine formations, but large chunks of this rock exist at numerous locations throughout the canyon. Travertine forms when groundwater percolates through limestone bedrock, which, of course, is abundant at Grand Canyon. The percolating water slowly dissolves the limestone, charging the water with dissolved calcium and carbonate. When the water emerges from the ground at a spring it loses carbon dioxide, driving a chemical reaction that causes the calcium and carbonate to rebond and to form a new limestone deposit known as travertine. Many of the travertine deposits contain evidence of their relationship to the Colorado River at the time of their formation. Therefore, if one could date the travertine, it would be possible to reconstruct from these rocks when and how fast the river has been carving the canyon since their formation.

A recent technological innovation that allows scientists to date travertine deposits is called uranium series dating. This radiometric dating technique, similar to the more familiar carbon 14 technique, can be applied to travertine deposited within the last one million years. The precision of the technique is very good for deposits less than about 450,000 years old, with the age determinations for older rocks being less precise. We have been using the uranium series technique to date travertine deposits that lie either on the Tonto Platform or in the Inner Gorge between Hermit and Boucher canyons. Field evidence indicates that the travertine deposits confined to the Tonto Platform were formed where the springs issued from a cliff wall at river level, which at that time lay at the elevation of the Tonto Platform. Therefore these travertines pre-date the carving of the entire Inner Gorge. Successful dating of these rocks would constrain when and how fast the Inner Gorge was cut. Conversely, the travertine deposits that presently spill down the walls of the Inner Gorge to within about 150 feet of the modern river level provide a minimum age for the carving of the gorge to that level. Spring waters cannot tumble down into a gorge that has not yet been carved. So, by dating these two separate groups of travertine deposits, we can bracket the age and rate of cutting of the Inner Gorge.

We are currently engaged in the analysis necessary to obtain reliable age information from the travertine samples. The travertine deposit that tumbles the farthest down the walls of the Inner Gorge has yielded a reliable age of 393,000 years, plus or minus 32,000 years. Geologists think a little differently than most folks. We can live with being off on our age estimate by a "small" number like 32,000 years. This means that by 393,000 years ago, the Inner Gorge was already nearly as deep as it is today.

Our next project is to get a reliable date on the older travertine deposits that pre-date the cutting of the Inner Gorge. We have one date so far, and it is tantalizingly interesting. Our job now is to ensure that it is reliable by replicating the result for additional samples. The date we

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Alternating layers of travertine (lighter material) and conglomerate. NPS photograph

GRAND CANYON'S

First Annual Herbarium Festival

By Katie Watters, Inner Canyon Vegetation Specialist, National Park Service

This past year of abundant winter moisture and near normal summer rains coaxed a myriad of plants out of hiding for a record wildflower year at Grand Canyon National Park. Most people appreciate the delicate beauty of a sacred datura flower unfurling in the pale glow of evening. But how many are drawn to the same flower after it has been dried and pressed, forever relegated to two-dimensional status with its gossamer petals clinging to the page as fragile as a piece of antique lace? Few value the beauty and importance of pressed plants, except the botanists who use them.

Herbarium specimens serve as reference tools to anyone working with any aspect of plants: botanists, ecologists, archeologists and even park visitors, who use herbarium information indirectly through guidebooks. Herbaria are a record of plant species for a given area, providing information on plant distribution, flowering and fruiting times, and species diversity. They preserve individual plants as a historical reference, a snapshot in time. Collecting plants and maintaining herbaria sheds light on the incredible complexity and diversity of vegetation in Grand Canyon, an area that is still understudied.

After a plant is collected and pressed between cardboard, blotting paper, and newspapers, botanists use taxonomic keys to discover its identity. Many plants in the Grand Canyon do not fit neatly into these existing keys. The diverse topography, microhabitats and isolation contribute to hybridization and speciation, making it critical for botanists to research and document plants to reveal their sometimes complicated identities. Once identified, each specimen is attached to archival paper along with a label that lists the identity of the collector, the date of collection, and the locality. These labels also answer questions about a plant's habitat. What other plants were its associates? Can it be found in the ponderosa pine forest or the desert scrub? Does it live in shady alcoves or does it need to have its roots wet?

For botanists, these sheets are like flipping through old photo albums and looking fondly at a picture of a great aunt that people always told illustrious stories about at family gatherings. The specimen sheets help botanists remember an encounter with a rare plant many years ago on a collecting trip.

Many people do not know that Grand Canyon has its own herbarium with more than 10,000 plant specimens, the oldest mount dating back to 1928. These document early collecting expeditions by National Park Service naturalists such as Polly Meade, Eddie McKee, and the first designated botanist of Grand Canyon, Rose Collom. Historic specimens reside with others that were collected only months ago by today's vegetation program staff and research botanists.

This collection documents the tremendous diversity of Grand Canyon plants, a handful of which grow nowhere else in the world. The canyon's plants represent nearly half of Arizona's flora, which is the fourth most botanically diverse state in the United States. Grand Canyon is home to 1,636 plant species. This is not a static number, but grows continuously. In just one month this last spring, during tamarisk monitoring in remote tributaries as well as backcountry trail and campsite surveys, thirteen plants were identified that had never previously been documented. For many of us who love the canyon, this surprising number of new discoveries adds to the mystique of this vast landscape and offers incentive to continue to cover more ground, searching out the nooks and crannies where other new plants may be hiding.

To celebrate this banner year of botanical discoveries, Colleen Hyde, Grand Canyon Museum Collection Technician, and the park's Inner Canyon Vegetation Program hosted volunteers from the Desert Botanical Garden in Phoenix and Northern Arizona University's Deaver Herbarium. In what will go down in park history as the First Annual Herbarium Festival, ten volunteers committed 370 hours to mount the 1,125 specimens that were waiting to join their comrades on archival paper in herbarium cases. The volunteers enjoyed sunsets along the rim, campfires, and songs, while working like summer camp crafters by day to get the job done. A hearty thanks to all who contributed to our knowledge of plants at Grand Canyon. We look forward to more botanical exploration and a Second Annual Herbarium Festival in 2006!

*A yucca specimen (*Yucca baccata*), leaf, flowers, and dried fruit, positioned on an herbarium sheet. NPS photo*

have suggests that the pre–Inner Gorge travertine was formed sometime between 450,000 and one million years ago. As mentioned above, scientists have to accept a much larger range of age uncertainty when we apply the uranium series technique to rocks older than 450,000 years, but knowing that this travertine is younger than one million years and older than 450,000 years is still a big step forward in terms of our knowledge of the history of Grand Canyon erosion. If this age is corroborated by analyses of other samples, it means that most of the canyon's Inner Gorge was carved out by the river at a geologically rapid rate between one million years ago and 400,000 years ago, with the pace of excavation slowing to a relative crawl since then.

There are a variety of possible explanations for this dramatic decrease in the Colorado River's quarrying activities. The way to differentiate between the possibilities is to bring our knowledge of the river's incision history into even sharper focus at as many locations along the length of Grand Canyon as possible. Geologists are employing various techniques on every rock that might provide a clue in order to obtain just such a clear incision history. The study of additional travertine outcrops will likely play an important role in adding detail to that history, which will in turn help us to understand how and why the Colorado River carved the canyon when it did.

Travertine flowing into the Inner Gorge. NPS photograph

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