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New Geologic Mapping of Petrified Forest National Park Aids in Understanding Evolution of Land Animals in Arizona

Jason J. Raucci, Ronald C. Blakey, and Paul J. Umhoefer

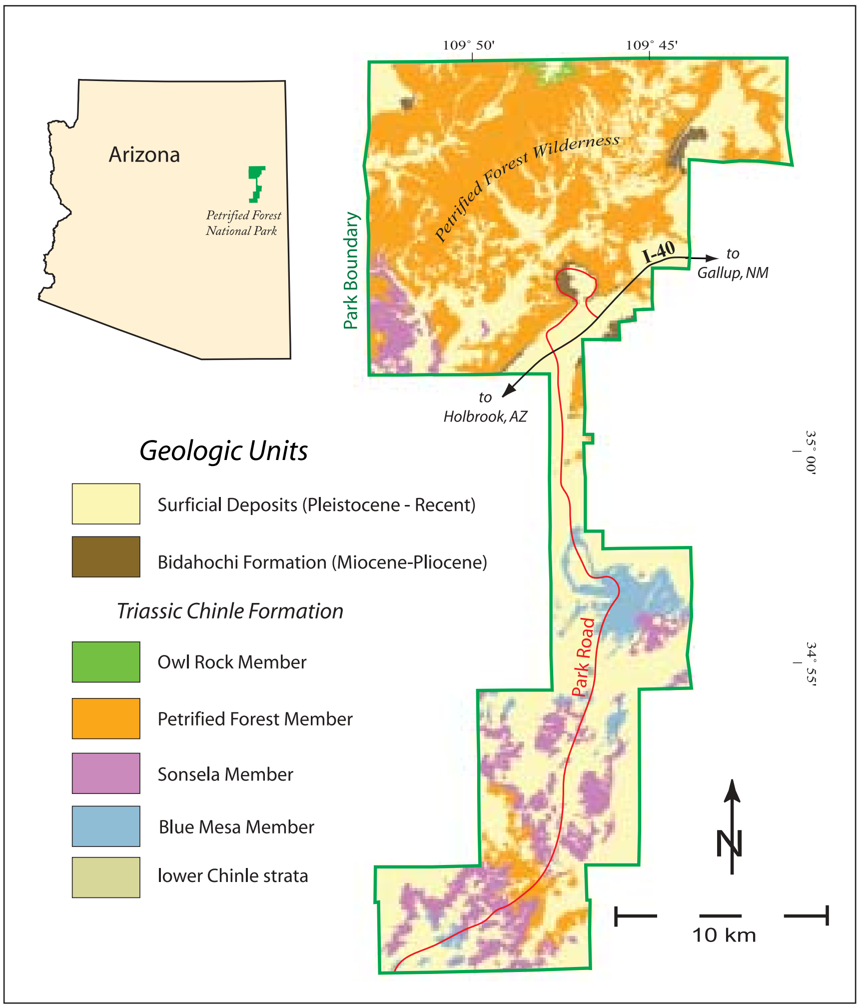

Figure 1. Location and simplified geologic map of Petrified Forest National Park.

The logo of the Arizona Geological Survey is a simplified geologic map that includes Arizona divided into three regions. The northeast region is the Colorado Plateau, a land of uplifted but flat-lying to gently inclined, layered sedimentary rocks such as seen in the walls of the Grand Canyon, and of young volcanic rocks like those seen around Flagstaff, Show Low and Springerville. The southwest region is the Basin and Range province, an area of numerous small mountain ranges separated by flat to gently sloping valley floors that are typically underlain by thick deposits of sand and gravel. Phoenix and Tucson are within the Basin and Range province. Between the two regions is the Transition Zone, a northwest-trending region that has some similarities to the other two but is distinctive in having widespread exposures of very old bedrock.

Petrified Forest National Park (which goes by the shorthand "PEFO" in National Park Service jargon) lies in the Colorado Plateau province of northeastern Arizona. The geology of the Little Colorado River Valley in eastern Arizona, including the PEFO area, is characterized by widespread exposures of Triassic and Jurassic sedimentary rocks. The Triassic Chinle Formation constitutes the bulk of the bedrock exposures within PEFO (Fig. 1). The Chinle Formation strata in PEFO consists of ~300 meters (1000 feet) of mudstone and sandstone that are interpreted as the deposits of major river systems (e.g. Deacon, 1990; Johns, 1988; Woody, 2003), originating perhaps in what is now the south-central United States (Riggs et al., 1996). These rocks were deposited approximately 205-220 million years ago in a variety of lowland terrestrial environments including river channels, floodplains, swamps, and small lakes (e.g. Johns, 1988; Tanner, 2000; Woody, 2003). Tributary streams from highlands to the south also likely joined the system in the vicinity of Petrified Forest (e.g. Deacon, 1990). Sedimentologic and paleontological observations in PEFO suggest an increasingly arid Late Triassic climate and a transition through time from perennial streams to mostly ephemeral streams (Johns, 1988; Woody, 2003).

Mission

To inform and advise the public about the geologic character of Arizona in order to increase understanding and encourage prudent development of the State's land, water, mineral, and energy resources.

Activities

Public Information

Inform the public by answering inquiries, preparing and selling maps and reports, maintaining a library, databases, and a website, giving talks, and leading fieldtrips.

Geologic Mapping

Map and describe the origin and character of rock units and their weathering products.

Hazards and Limitations

Investigate geologic hazards and limitations such as earthquakes, land subsidence, flooding, and rock solution that may affect the health and welfare of the public or impact land and resource management.

Energy and Mineral Resources

Describe the origin, distribution, and character of metallic, nonmetallic, and energy resources and identify areas that have potential for future discoveries.

Oil and Gas Conservation Commission

Assist in carrying out the rules, orders, and policies established by the Commission, which regulates the drilling for and production of oil, gas, helium, carbon dioxide, and geothermal resources.

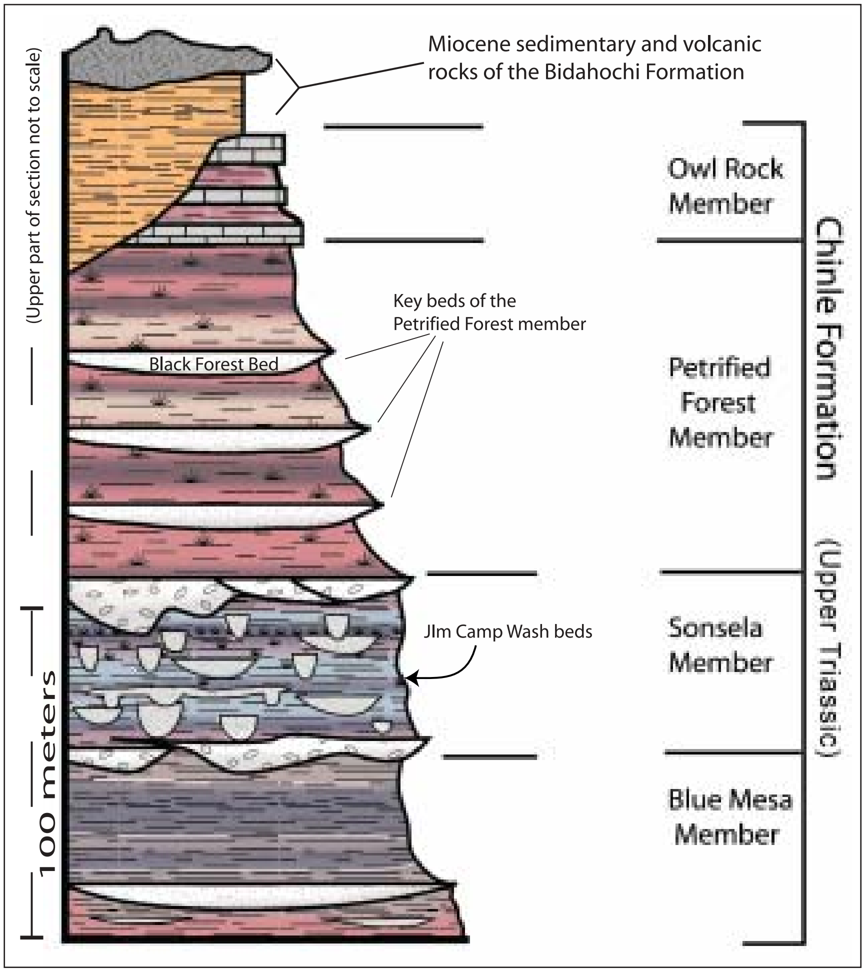

Figure 2. Schematic stratigraphic column of rocks exposed in Petrified Forest National Park. The complete section is approximately 300 meters thick, but upper members are not to scale in this schematic diagram. Modified from Woody (2003).

Geologic mapping at PEFO

Geologic maps show the distribution of geologic units and can help researchers infer the relationships between these units. A geologic map is the starting point for understanding the regional distribution of rock types, locating important stratigraphic layers, and understanding the geologic history of an area. Although a large body of geologic data exists regarding the Chinle Formation within PEFO, there is currently no published geologic map of the entire park. The U.S. Geologic Survey has discontinued a comprehensive geologic mapping program and has no plans to publish the preliminary map completed by George Billingsley (of the USGS) in 1985. Comprehensive maps are essential for many types of geologic research. In particular, understanding complex stratigraphic relations such as those in the Chinle Formation at PEFO must rely on knowledge of the lateral relations between geologic units. We believe it is no coincidence that despite over 100 years of study, there is only now an emerging consensus regarding the proper manner to subdivide and name the major sub-units of the Chinle Formation within PEFO (Heckert and Lucas, 2002; Woody, 2003, this study).

Measured sections and geologic maps

Sedimentary rocks such as those exposed in PEFO are typically studied by means of *measured sections*, and displayed in a vertical column that represents the exposed rocks, with each distinct interval described in detail and symbolized on the column. Accurate mapping ties together disparate study localities and places individual measured sections in their correct regional context – i.e., it helps us understand how the rocks exposed in one location relate or correlate to those exposed in another. This is a key step in constructing a stratigraphic model that reflects the true geometry and distribution of the rock units. Conversely, when a stratigraphic model is constructed without comprehensive mapping, the tendency is to infer the distribution of key layers based on correlations between measured stratigraphic columns, without fully confirming those correlations. There are dozens of measured sections of the Chine Formation within PEFO available for scrutiny, but consensus among researchers on the proper scheme for correlating and naming distinctive intervals has remained elusive. The lack of a single complete map thus encourages a proliferation of competing stratigraphic interpretations and nomenclature, as has been the case in PEFO (Woody, 2003). In a sense, the construction of a stratigraphic model and geologic map is an iterative process in which the inferences gathered from measured sections are tested against the true distribution of rock types. Thus, the lack of an accurate map has until now hindered our ability to understand the stratigraphy of the Chinle Formation in PEFO and the surrounding areas of the Colorado Plateau.

Mapping the Chinle Formation

Our stratigraphic model is summarized by the schematic column in Figure 2. The four major divisions ("members") of the Chinle Formation we recognize in PEFO are from lowest to highest: Blue Mesa Member, Sonsela Member, Petrified Forest Member, and Owl Rock Member. These major divisions are further subdivided into "key beds", smaller stratigraphic intervals that are distinct and laterally persistent. Key sandstone marker beds within members were identified where they mark the transition between members, or an important horizon within a member, and/or contain significant paleontological resources that may be the subject of research in their own right (e.g. the Black Forest Bed).

It is not known if any of the key beds mapped within the Sonsela and Petrified Forest members in the north half of PEFO correlate directly to key beds in the south half. This is because complex stratigraphic relations between the two areas are obscured by surficial deposits and a lack of continuous exposure. We have chosen to map significant, laterally continuous, and unit-bounding sandstones within the Sonsela member and lower part of the Petrified Forest member north of Interstate 40 using a slightly different model from that of the south half of PEFO until the relationship between the stratigraphy of the northern and southern areas is better understood.

By mapping major subdivisions and locally designated key beds, we have endeavored to accurately represent the rock units without implying potentially dubious stratigraphic correlations between localities. Members of the Chinle Formation were mapped throughout the Park, but key beds were, in general, mapped only where their continuity could be established with reasonable certainty. In some cases, broad intervals were mapped rather than individual key beds. For example, the Jim Camp Wash "beds" are actually a distinctive interval of interbedded sandstone and mudstone with diagnostic cut-and-fill internal architecture, and are mapped as one unit throughout PEFO.

Significance for paleontology

The lower part of the Chinle Formation in PEFO was deposited during the Carnian and Norian stages – two subdivisions of the Late Triassic System. The boundary between these two time periods represents a significant, globally recognized change in the assemblage of fossil animals. This boundary is generally thought to be represented by an unconformity, or break in the geologic record, within or at the base of the Sonsela Member (Heckert and Lucas, 2002; Woody, 2003). Accurate mapping will help paleontologists determine if new fossil localities lie below, near, or above this important boundary and thus increase our knowledge of the evolution of land animals at the dawn of the age of dinosaurs.

Although the rocks at PEFO contain one of the most complete records of land-animal evolution across the Carnian-Norian boundary, until recently this rich paleontologic record has not been tied into a comprehensive stratigraphic model. Once the evolutionary sequence of fossil fauna is accurately tied to the sequence of sedimentary rocks, this knowledge can be applied to other fossil localities and thus provide an estimate of the age of the rocks in areas where the stratigraphy is not well known. This dataset is called a *biostratigraphy*. Regional to global biostratigraphic correlations are mainly based on marine fossils, but tying the marine record to terrestrial deposits such as the Chinle Formation is essential for a complete understanding of the past. The creation of a Triassic biostratigraphy based on land-dwelling vertebrates has been a major goal of paleontologists working in the Chinle Formation (Heckert and Lucas, 2002). Geologic mapping utilizing an accurate and broadly applicable stratigraphic model will be a vital supporting dataset in this ongoing research effort.

We feel this map represents a significant step forward for geologic studies in and near Petrified Forest National Park, and for general studies of the Chinle Formation and the Triassic Period in northeastern Arizona. It will also serve as a critical reference for future studies as the Park is expanded to encompass nearby significant exposures of the Chinle Formation.

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[Jason Raucci (Jason.raucci@nau.edu) is a geologist with Clear Creek Associates in Tucson, Arizona. This article is based on work he did as Research Associate at Northern Arizona University, in Flagstaff. Ronald Blakey and Paul Umhoefer are professors in the Department of Geology at NAU.]

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Woody, D., 2003, Revised geological assessment of the Sonsela Member, Chinle Formation, Petrified Forest National Park, Arizona: [MS Thesis], Northern Arizona University, Flagstaff, 206 p.

New Publications

Geologic map of the Flatiron Mountain 7.5' quadrangle, Maricopa County, Arizona: Spencer, J.E., Youberg, Ann, and Ferguson, C.A., 2006, Arizona Geological Survey Digital Geologic Map 46, v. 1.0 (DGM-46), 1 CD-ROM that includes a 1:24,000-scale map. $15.00 plus tax (Arizona residents) and shipping charges. A color paper copy of the map is available for $13.00 plus tax (Arizona residents) and shipping charges.

Geologic map of the Wintersburg 7.5' quadrangle, Maricopa County, Arizona: Pearthree, P.A., Ferguson, C.A., and Harris, R.C., 2006, Arizona Geological Survey Digital Geologic Map 47, v. 1.0 (DGM-47), 1 CD-ROM that includes a 1:24,000-scale map. $15.00 plus tax (Arizona residents) and shipping charges. A color paper copy of the map is available for $13.00 plus tax (Arizona residents) and shipping charges.

Geologic map of the Saint David 7.5í quadrangle, Cochise County, Arizona: Youberg, Ann, 2006, Arizona Geological Survey Digital Geologic Map 48, v. 1.0 (DGM-48), 1 CD-ROM that includes a 1:24,000-scale geologic map. $15.00 plus tax (Arizona residents) and shipping charges. A color paper copy of the map is available for $13.00 plus tax (Arizona residents) and shipping charges.

Geologic map of the Land 7.5' quadrangle, Cochise County, Arizona: Shipman, T.C., and Ferguson, C.A., 2006, Arizona Geological Survey Digital Geologic Map 49, v. 1.0 (DGM-49), 1 CD-ROM that includes a 1:24,000-scale geologic map. $15.00 plus tax (Arizona residents) and shipping charges. A color paper copy of the map is available for $13.00 plus tax (Arizona residents) and shipping charges.

Geologic map of the Fairbank 7.5' quadrangle, Cochise County, Arizona: Ferguson, C.A., Shipman, T.C., Pearthree, P.A., Moore, E.M., Richard, S.M., and Spencer, J.E., 2006, Arizona Geological Survey Digital Geologic Map 50, v. 1.0 (DGM-50), 1 CD-ROM that includes 13 p. text and a 1:24,000-scale geologic map. $15.00 plus tax (Arizona residents) and shipping charges. The text and a color paper copy of the map are available for $14.00 plus tax (Arizona residents) and shipping charges.

Geologic map of the Lewis Springs 7.5' quadrangle, Cochise County, Arizona: Pearthree, P.A., Ferguson, C.A., and Demsey, K.A., 2006, Arizona Geological Survey Digital Geologic Map 51, v. 1.0 (DGM-51), 1 CD-ROM that includes 11 p. text and a 1:24,000-scale geologic map. $15.00 plus tax (Arizona residents) and shipping charges. The text and a color paper copy of the map are available for $13.00 plus tax (Arizona residents) and shipping charges.

Reconnaissance assessment of the geothermal potential of San Bernardino Valley, Cochise County, Arizona: Stone, Claudia, and Witcher, J.C., 2005, Arizona Geological Survey Contributed Report 05-A (CR-05-A) [originally prepared December 1982], 76 p. $17.50 plus tax (Arizona residents) and shipping charges.

—continued on page 6

Earth fissure legislation approved

Governor Napolitano signed into law HB2639, the "earth fissure maps" bill one day after unopposed approval by the Arizona Legislature at the end of the 2006 session. The new law was crafted by Representatives John Nelson of Phoenix, and Wade Nichols of Chandler, in response to public concerns after a large fissure re-opened almost overnight in a residential area southeast of Phoenix during last August's monsoon rains.

Earth fissures start out as relatively narrow cracks at the surface, often only an inch or so across, that may extend down tens to hundreds of feet into valley sediments, and run across the countryside for up to a few miles. But as water enters the fissures, it easily erodes the surface soils and carries them to deeper areas, and a wide chasm can open at the surface in just hours. The eroded fissure gullies can easily be 10-20 feet across and 5-30 feet deep. Many mature fissure gullies have captured local drainages, eroded them into fissure gullies, filled them with sediments, and now serve as washes, which can disguise their true origin and potential hazard.

Although earth fissures have been known and documented for decades, many occurred in rural areas and were more a curiosity than a threat. Rapid population growth in recent years, however, is resulting in new homes and subdivisions having to deal with the earth-fissure hazard. AZGS has produced a dozen sets of maps of earth fissures in different areas of the state over the past 15 years, but at the scale of 1:24,000 they are generally not sufficiently detailed to determine the hazards to individual properties or homes. Some areas of reported fissures have not been mapped at all and in mapped areas, new fissures open up or extend their length, requiring new mapping. Budget cuts in the 1990s reduced the AZGS ability to continue working on the fissure hazard.

The new law directs the Arizona Geological Survey to produce detailed maps of earth fissures and work with the State Land Department and Department of Real Estate to post the maps online in user-friendly formats linked with other map layers that allow users to easily evaluate individual properties of interest.

Concerns about fissures brought together representatives from businesses, state agencies, and consumers at the request of Rep. Nelson throughout last fall. HB2639 grew out of those discussions. It drew support from a politically unusual coalition including the Arizona Association of Realtors, the Homebuilders Association of Central Arizona, the Sierra Club, and the Nature Conservancy. With that broad support, the bill passed the Arizona House 52-0, and the Senate 27-0.

A key element of the bill provides funding for the AZGS to put three geologists to work full time mapping earth fissures and disseminating the results. Because of the urgency of this public safety issue, we are redirecting some of our existing staff to begin work on mapping fissures immediately, while we gear up with additional staff to take on this new responsibility that is funded as of September 2006. One-time funds are also made available for high precision GPS equipment to accurately and precisely locate the fissures.

The AZGS is developing a four-part approach to fissures. One is to map the fissures. Two is to disclose the fissure information through our partnerships with our sister state agencies, State Land and Real Estate. Three is to educate homeowners and buyers, real estate professionals, builders, and local government officials on the nature and occurrence of fissures and how to use the new maps we are developing. Four is to work with local government officials and builders on how to mitigate the impacts of fissures.

We have seen cooperation during the past year among all the parties affected by the fissure hazard that augurs well for improving public safety and protecting home- and property-buyers. AZGS is excited to again have the resources to get back to work on this critical program.

M. Lee Allison

New Publications—continued from page 4

A CO_2-silica geothermometer for low temperature geothermal resource assessment, with application to resources in the Safford Basin, Arizona: Witcher, J.C., and Stone, Claudia, 2005, Arizona Geological Survey Contributed Report 05-B (CR-05-B) [originally prepared November 1983], 154 p. $34.00 plus tax (Arizona residents) and shipping charges.

K-Ar dates of fault rocks along the Catalina detachment fault, Tanque Verde Ridge, Rincon Mountains, Arizona: Damon, P.E., and Shafiqullah, Muhammad, 2006, Arizona Geological Survey Contributed Report 06-A, v. 1.0 (CR-06-A), 17 p. $5.50 plus tax (Arizona residents) and shipping charges.

A geologistís guide to the core complex geology along the Catalina Highway, Tucson area, Arizona: Spencer, J.E., 2006, Arizona Geological Survey Open-File Report 06-01, v. 1.1 (OFR 06-01), 38 p. $9.50 plus tax (Arizona residents) and shipping charges.

Surficial geology and fire in southeastern Arizona grasslands - Effects on soil geochemistry in semiarid ecosystems, Fort Huachuca Military Reservation, Arizona: Biggs, T.H., Pearthree, P.A., Florkowski, L.N., and Shaner, P-J.L., 2006, Arizona Geological Survey Open-File Report 06-02 (OFR 06-02), includes 50 p. text and 1 CD-ROM. $17.00 plus tax (Arizona residents) and shipping charges.

AZGS WEBSITE

The Arizona Geological Survey website, www.azgs.az.gov, provides geologic information (including geologic hazards), lists publications and maps for sale, contains the most recent Arizona Geology issues, has staff listing, and much more.

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ARIZONA GEOLOGICAL SURVEY
416 West Congress, Suite 100
Tucson, AZ 85701
Phone: (520) 770-3500 Fax: (520) 770-3505

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