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Field Guide 55

# *Accessibility and inclusion in the field: A field guide for central Arizona and Petrified Forest National Park*

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## ABSTRACT

**This field trip focuses on accessible and inclusive design in field-based teaching and learning through a broad investigation of the geology of Arizona, followed by more detailed exercises that focus on the Upper Triassic stratigraphic sequences in Petrified Forest National Park (PEFO). The first day of the field trip will traverse the three physiographic provinces of Arizona, from fault-bounded, basement-cored uplifts and valleys of the Basin and Range in the greater Phoenix area, through the Transition Zone to the Mogollon Rim, and ending in Upper Triassic sedimentary rocks of the Colorado Plateau at Holbrook. The second day of the field trip will encompass more detailed, collaborative exercises in PEFO that utilize the expertise of both student and faculty participants in mixed-ability groups. The main priority of this accessible field experience is the development of an inclusive community of learning driven**

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**by paired student-faculty interactions, facilitated as needed by technology integration to mitigate barriers and foster engagement, communication, and collaboration across a spectrum of ability and content knowledge.**

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***Please note that the collection of archaeological artifacts, fossils, rocks, or other natural history objects without an active research and collection permit is illegal at Petrified Forest National Park. Please refrain from collecting samples or specimens of any kind from anywhere in the park.***

## INTRODUCTION

Fieldwork is widely considered to be one of the most effective ways of learning in the geosciences (Ernst, 2006; Nyman et al., 2008). At their most fundamental, field studies enable learners to contextualize knowledge through direct interaction with the physical environment, and to develop the skills and expertise characteristic of geoscience practice (Butler, 2008; Whitmeyer et al., 2009). Field studies also play a vital role in developing a learner's personal identity as a geoscientist by immersing them in an environment where they can actively collaborate with both experts and peers, and "learn to do what geoscientists do" (Petcovic et al., 2014, p. 4). Unfortunately, students with disabilities, and particularly those with limited mobility, may choose to avoid programs with a component of fieldwork due to the perceived inaccessibility of participating in the often rigorous learning experiences (Cooke et al., 1997; Hall et al., 2004).

The geosciences have traditionally attracted a limited number of learners with disabilities (AGI, 2009). This lack of engagement is perhaps perpetuated by a range of factors, including the way the geoscience discipline is promoted (Sexton et al., 2014), and the pedagogical knowledge needed to accommodate students with diverse needs and abilities in the classroom and field environments (Norman, 2002). Geoscience instructors are often faced with the challenge of providing accommodations on the fly, with limited institutional support (Feig et al., 2019) when students with various disabilities arrive in their courses (Atchison and Libarkin, 2013). Making major modifications to the curriculum after student needs are known is neither effective nor necessary. All students' needs can be accommodated with minimal changes at the activity level when initial pedagogical planning intentionally focuses on specific learning objectives that are both inclusive and accessible. Thus, when possible, a deliberate collaborative planning meeting with the student who will utilize the accommodations can address any minor modifications.

The traditional focus on the field-based teaching and learning marginalizes both students and faculty who do not fit the "strong and able-bodied" model of a rugged practitioner (Locke, 2005, p. 2). Rather than viewing students with disabilities as a liability in field environments, geoscience programs are missing opportunities to strengthen a learning community by designing accessible and inclusive opportunities for all students to collaborate and share alternative perspectives of the field. Healey et al. (2002) identified three main barriers to overcome in the design of inclusive field courses:

- Attitudinal: personal attitudes of staff, other students, and the general public.
- Organizational: course requirements, time constraints, institutional regulations.
- Physical: site access, supporting materials.

To be truly inclusive, field-based instruction should be modified and adjusted in a planned, student-centered manner to accommodate students with disabilities in the natural environment where geology can be experienced in situ and in context. Recent studies have shown how explicit inclusion can lead to academic success for students with disabilities in geoscience instruction (Atchison, 2011; Feig et al., 2019) and across the entire learning community (Atchison et al., 2019; Gilley et al., 2015; Hackman and Rauscher, 2004; Healey et al., 2006), while also maintaining high standards of rigor within the curriculum (Cooke et al., 1997).

### Accessible and Inclusive Field Learning

Accessible and inclusively designed field experiences are intended to enable students with disabilities to participate in all field-related activities, develop a geoscience identity, and broaden interest in the natural environment. Accessible field experiences are not designed to be typical geology field trips, in the traditional sense. Neither are they meant to merely *show and tell* the geology content. They are experiential learning opportunities for geoscience student and faculty participants, paired across ability types, collaborating on typical field-related tasks, and sharing expertise on both geology content and physical, sensory, and social accessibility within an inclusive community of learning. Through this paired approach, all participants will become more familiar with common barriers to active participation in field courses and begin to consider strategies for developing inclusive learning communities.

Every accessible field trip offered by the International Association for Geoscience Diversity (IAGD) held during Geological Society of America (GSA) meetings has three primary objectives: (1) to provide a fully inclusive, field-based learning experience for students and faculty across a spectrum of abilities (e.g., physical/orthopedic/mobility, deaf/hard-of-hearing, blind/low-vision, cognitive, and developmental disabilities, such as autism); (2) to provide a unique training opportunity for geoscience instructors learning how to accommodate students with disabilities in geoscience field courses; and (3) to extend the network of participants and resources developed from previous accessible field trips, courses, and research projects. These objectives have driven the collaborative nature of recent accessible geoscience field trips where all participants are engaged in a socially inclusive community of learning, working with, and learning from the diverse perspectives and experiences of everyone involved.

The 2019 GSA "Accessible Field Geology of Petrified Forest National Park" trip is no different. We will observe the regional geology of Arizona along the drive from Phoenix to Petrified Forest National Park (PEFO) and visit key localities of Mesozoic strata in the PEFO region with the goal of expanding approaches to providing inclusive, field-based learning experiences for students with disabilities. The trip emphasizes active learning and collaboration as participants consider their surroundings and make inferences about the geologic processes that have shaped, and continue to shape, each location. Modern technologies, such as mobile devices, are used to collect field data and interpret the geology, and can be used to facilitate communication and interaction among participants when necessary.

## Technology in the Field

A primary objective of this field trip is to increase engagement of students with disabilities in field environments and instill confidence in their ability to participate in authentic field investigations and research. This trip is designed to include a mixed-ability group of undergraduate and graduate students, geoscience faculty, and other participants both with and without disabilities. Participants are assembled into smaller working groups, in which they make use of mobile (and other) technologies to facilitate inclusive group work. Primary tasks in the field focus on key exposures of Triassic strata, where participant teams will observe and characterize the rock units and stratigraphic sequences, assemble detailed stratigraphic sections and logs, and evaluate the outcrops in the context of the regional geology.

Previous work on access and inclusion in the field has highlighted the importance of establishing an inclusive learning community, where all participants are involved in fieldwork and interacting with other team members in real time (Atchison et al., 2019; Collins et al., 2010, 2016). To facilitate this, we have developed a technology-based approach that uses real-time audio and audio-visual communication to connect students that may be physically separated across field sites, and with various types of access challenges. Modern mobile video-streaming apps (e.g., AirBeam) and photo-sharing apps (e.g., PhotoSync) can facilitate real-time interaction between team members, given a robust cell signal or a local area network (LAN). More traditional methods of communication, such as two-way radios, can also be effective, as long as team members have line-of-sight and are separated by a reasonably short distance (less than 1 mile).

Mobile apps are also useful to collect field data for tasks such as geologic mapping (e.g., FieldMove, StraboSpot; Walker et al., 2019), orientation measurements (e.g., FieldMove Clino, Stereonet Mobile; Allmendinger et al., 2017), and logging stratigraphic sections (e.g., Strat Mobile, StraboSpot). Recording field notes and sketches digitally is more of a challenge; however field-mapping apps (e.g., FieldMove, StraboSpot) allow for some note taking during data collection at outcrops. Dedicated note-taking apps (e.g., Notability) can be useful for recording field notes. Sketches and photo annotations are possible with the native camera on a mobile device, coupled with Notability or a sketching app (e.g., Skitch). Digital products can be shared among team members with cloud-based storage apps (e.g., DropBox or Google Drive) during times when a cell signal or Wi-Fi is available.

In situations where real-time communication and interaction are not possible (e.g., no cell signal, physical separation by a great distance, or intervening obstacles), field-data collection and observations can be recorded asynchronously and offline. This can be accomplished with wearable video-recording devices (e.g., GoPro video cameras). Alternatively, mobile devices typically come with GPS sensors, cameras, and apps that can record photos and videos along with location information, and many apps can store data on a mobile device for later sharing and/or uploading to cloud-based storage. These data can be shared with group members when groups reassemble at a previously agreed upon time and location. This asynchronous approach is less desirable than real-time interaction, but is often necessary due to typical constraints inherent in remote field sites. In our experience, a combination of real-time and asynchronous communication and interactions among group members is often the most effective approach to inclusive fieldwork.

For this accessible and inclusive field experience, we are using iPads for both real-time and asynchronous interaction and data collection at roadside outcrops and at more remote field locations at PEFO. The geologic tasks focus on analyzing and comparing well-exposed outcrops and stratigraphic sections. In addition to useful native iPad features and apps (e.g., Photos, Notes, and others) our mobile app library includes AirBeam for real-time video communication and PhotoSync for near real-time photo transfer. These apps can also store videos and photos on the mobile device for sharing at a later date. GoPro cameras are available for asynchronous video documentation of the outcrops and group interactions. For collection of geologic field data, such as orientation measurements, lithologic information, and stratigraphic data, we are using mapping-focused apps (e.g., StraboSpot, Strat Mobile). Field notes, sketches, and photo annotations are recorded using a note-taking app (e.g., Notability). During any field experience, depending on specific field conditions, requirements, and scenarios, a subset of the apps highlighted above will likely prove useful to teams and team members collaborating across distance or ability type.

## Discussion

Field-trip facilitators of any accessible field trip should be prepared to address the three primary barriers of field-based teaching and learning as presented by Healey et al. (2002) and described above: attitudinal, organizational, and physical. To do this, trip leaders should remain flexible, focus on the primary learning objectives at each field-site stop location, and design activities that enable the participation of all by first considering the expertise of those needing accommodations. Physical and social barriers are most common in any field experience and should be first addressed by deliberately encouraging the active participation and collaboration across inclusive communities of learning. Students and faculty alike should realize that full participation does not necessarily mean 100% participation in all activities, but rather means inclusion of all participants in the learning of each activity by holding whole-group instruction and debriefing sessions.

During each activity, instructors should prime inclusive dialogue by posing broad overview questions to encourage all participants to think about the geoscience content from the perspectives of physical access to the science, as well as the diverse perspectives within the entire learning community. This focus on physical accessibility, content engagement, and inclusive social interaction across diverse participant experiences and abilities ultimately drives the social construction of knowledge (Vygotsky, 1978).

The use of mobile technologies to facilitate inclusive participation of all participants in the field experience is dependent on the physical barriers presented by the field environment, the unique abilities of the students, as well as the focused learning objectives for field-oriented tasks. Most of the PEFO site locations selected for this trip present few physical barriers to accessing outcrops, such that most participants can directly interact with the geology, regardless of mobility level. At locations where the learning objectives involve evaluation of a stratigraphic sequence of beds, the height of the section being investigated (tens of meters) requires observation from a distance. There is less need for participants to get closer to the features than the fully accessible parking areas, unless detailed observation of bed-level sedimentological structures is deemed necessary. Although cellular service is surprisingly strong throughout the areas of PEFO that are visited on this field trip, technology-mediated communication and remote data sharing are generally not required for participant teams to complete the trip activities. However, many remote locations within PEFO likely would require the use of mobile technologies for inclusive collaboration across distance and ability type.

## GEOLOGICAL BACKGROUND

The geologic history of Arizona began in the Paleoproterozoic Era at ca. 1800 Ma with the assembly of the continental lithosphere by accretion of island-arc terranes in sequential orogenic events (e.g., Whitmeyer and Karlstrom, 2007; Karlstrom et al., 2012), now recorded in the metamorphic and granitic rocks of the basement. The basement rocks range in age from ca. 1800 to ca. 1400 Ma and are prominent along the early and middle Day 1 segments of the field trip (shown in Fig. 1). The Paleoproterozoic orogen was eroded to a relatively flat surface by the Mesoproterozoic Era, and intracratonic rift basins formed across the region in response to the Mesoproterozoic assembly and Neoproterozoic disassembly of supercontinent Rodinia (e.g., Timmons et al., 2001). Sedimentary rocks deposited in these basins include the Mesoproterozoic Apache Group, exposed in the Sierra Ancha, visible to the east of the Day 1 field-trip route near Rye. Following the breakup of Rodinia and throughout the early and middle Paleozoic Era, ancient Arizona was a mostly low-relief region situated on the passive margin of supercontinent Laurentia. This region was subject to repeated cycles of transgression and regression that left behind a thick sequence of Lower Cambrian to Upper Permian limestones, mudstones, and sandstones, exposed along the Day 1 route below the Mogollon Rim.

The southwestern margin of Laurentia, which lay well to the west of Arizona, evolved from passive to transcurrent to convergent between the Pennsylvanian and Triassic, in part contemporaneous with collision of Gondwana with Laurentia to form the Pangean supercontinent. Along the southwestern margin, magmatism beginning at ca. 275 Ma (Arvizu et al., 2009; Riggs et al., 2010; Cecil et al., 2018) brought profound changes to sedimentary systems in the retroarc region. Most significant to this field trip, by ca. 235 Ma, or late Middle Triassic time, a terrestrial connection was established between the magmatic arc and retroarc region. The Chinle Formation contains the earliest major record of western Laurentian magmatism.

The main focus area of Day 2 starts in Holbrook (Fig. 1), which sits on the Lower–Middle Triassic Moenkopi Formation, and includes the Wupatki, Moqui, and Holbrook Members (McKee, 1954; Stewart et al., 1972a; Nesbitt, 2005). The Moenkopi Formation is overlain by the Chinle Formation, the basal member of which is the Shinarump Conglomerate (McKee, 1954; Stewart et al., 1972b). The Shinarump Conglomerate is not found within Petrified Forest National Park, but caps and overlies the Moenkopi Formation on some mesas seen on the drive from Holbrook to PEFO (Parker et al., 2013).

Strata within PEFO predominantly consist of the Upper Triassic Chinle Formation, a thick sequence of terrestrial sedimentary rocks. Sediments were deposited in river systems that were likely sourced in southern and western Arizona and to the southeast (Stewart et al., 1972b; Blakey and Gubitosa, 1983; Riggs et al., 1996; Howell, 2010; Riggs et al., 2012). The Chinle Formation in PEFO is divided into five members: in stratigraphic sequence from oldest to youngest they are the Mesa Redondo, Blue Mesa, Sonsela, Petrified Forest, and Owl Rock members (Fig. 2; Woody, 2006; Martz and Parker, 2010). In general, the Chinle Formation is highly fossiliferous with a diversity of plant and animal fossils. These include palynomorphs (microscopic plant and animal structures), leaves, and permineralized (petrified) wood, as well as terrestrial invertebrate and vertebrate animals (Ash, 2005; Irmis, 2005; Parker, 2005). The Mesa Redondo Member has limited exposure within the boundaries of the park, and we will not visit it on this field trip. The Mesa Redondo Member is overlain by fossiliferous bluish outcrops of the Blue Mesa Member, which we will view midway through our south-to-north traverse of PEFO (Fig. 3). The first outcrops we visit at the southern entrance of the park are cross-bedded sandstone and conglomerate (Jasper Forest/Rainbow Forest beds) in the middle of the Sonsela Member. These strata incorporate the famous petrified logs seen at our first stop on Day 2 and at the southern visitor center (Stop 2.3; Fig. 3). Other prominent beds of petrified logs seen in the park, such as

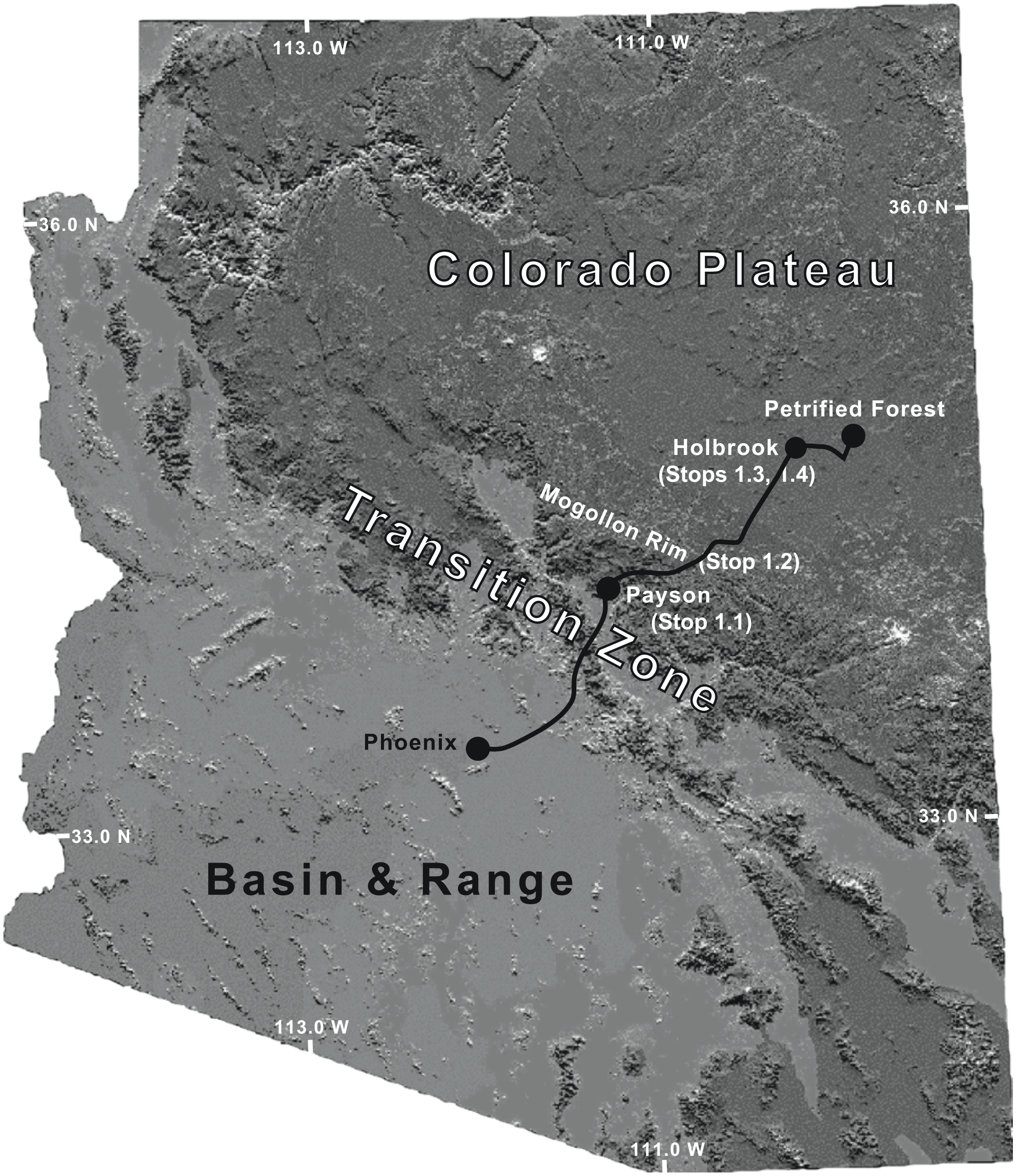

Figure 1. Relief map of Arizona, adapted from the U.S. Geological Survey, with generalized route of field trip indicated with black line. The physiographic provinces of the Colorado Plateau, Transition Zone, and Basin and Range are indicated with bold text. Key locations, such as the cities of Phoenix, Payson, and Holbrook, and Petrified Forest National Park, are indicated with black dots. Day 1 stop locations (1.1–1.4) are also indicated.

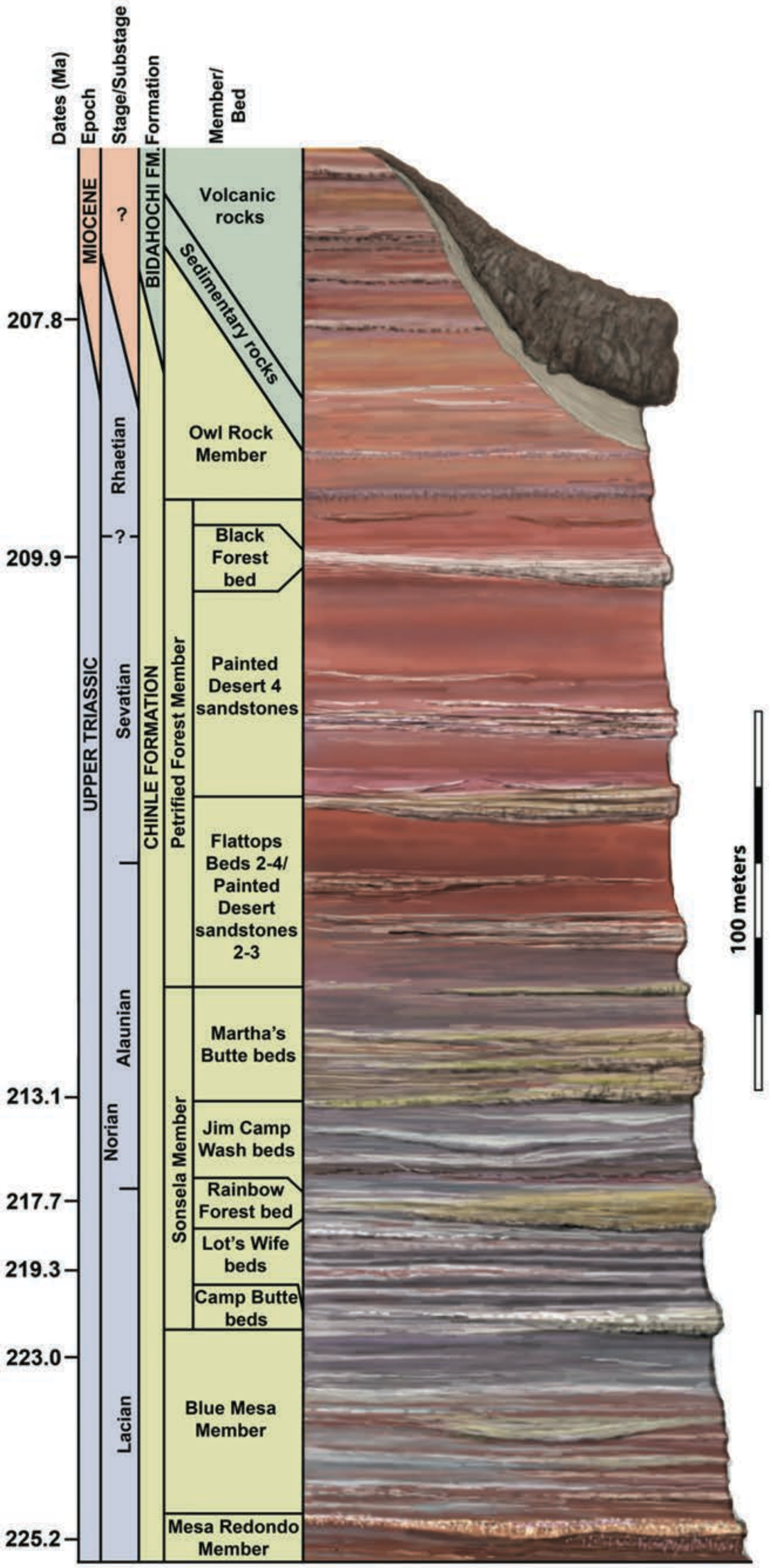

Figure 2. Lithostratigraphic column for Petrified Forest National Park, adapted from Martz et al. (2012); radioisotopic dates from Ramezani et al. (2011). Members of the Chinle Formation are indicated, from the Mesa Redondo Member at the base to the Owl Rock Member at the top. Volcanic rocks of the Bidahochi Formation are illustrated as unconformably overlying the top members of the Chinle Formation. Note that the relative colors of the various beds are indicated, but more significant is that the width of the column reflects the resistance of the beds to erosion; resistant sandstones extend farther to the right than less resistant mudstones and siltstones.

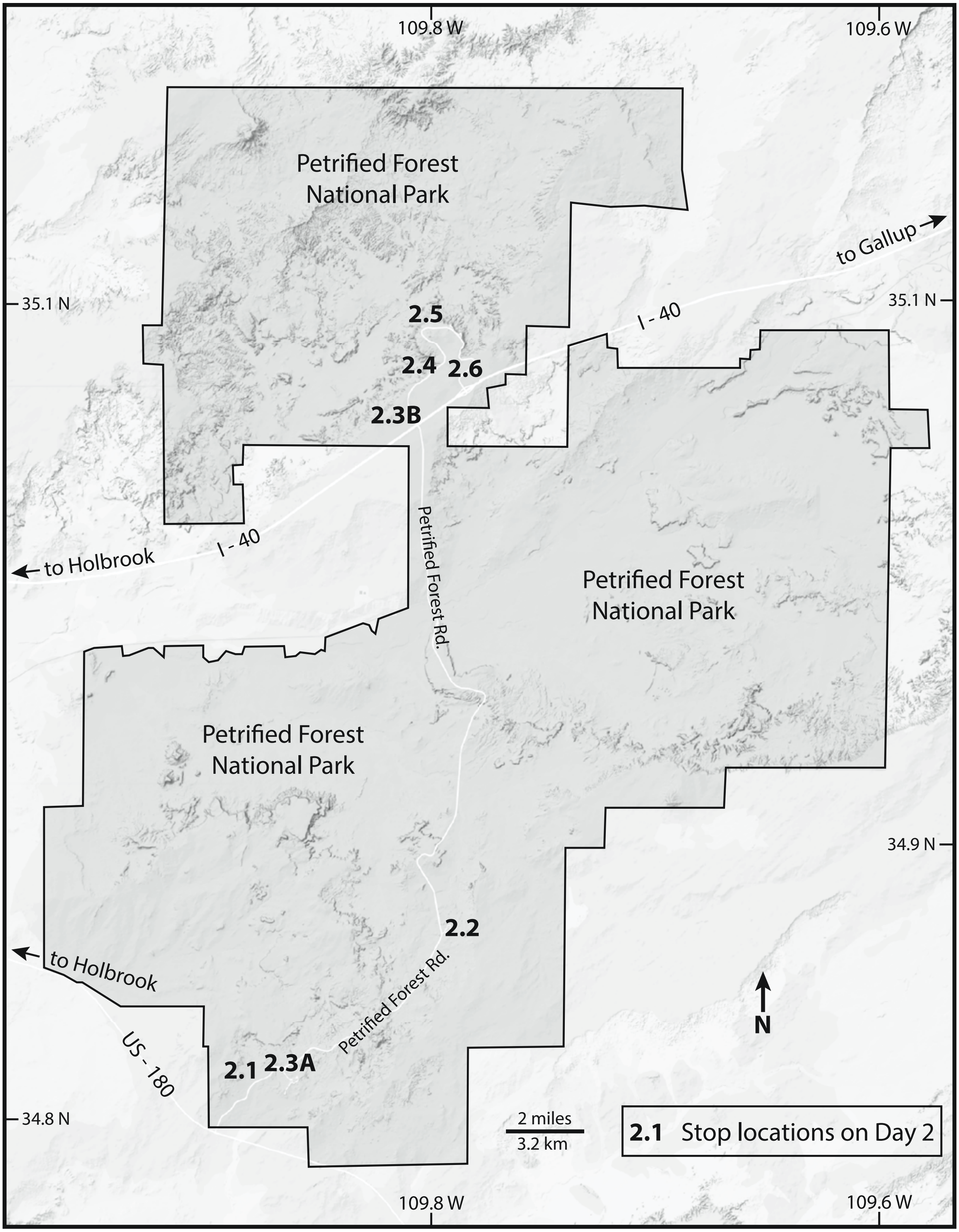

Figure 3. Shaded relief map of the Petrified Forest National Park area, with the areal extent of the park indicated by the darker polygon outlined in black. Day 2 stop locations are indicated by bold numbers (2.1–2.6). Background terrain map courtesy of Google Maps.

the Jasper Forest and the Kellogg Butte beds, are interpreted as the same stratigraphic level as the Rainbow Forest beds (Martz and Parker, 2010; Martz et al., 2012). Nearby buttes consist of the Jim Camp Wash beds, overlain by sandstones and interbedded siltstones of the Martha's Butte beds, which constitute the upper part of the Sonsela Member.

Farther north in the park, the Petrified Forest Member overlies the Sonsela Member, and consists of purple mudrocks at the base (the "monotonous purple beds" of Martz and Parker, 2010) overlain by several thick sandstone beds, the "Flattops" sandstones. Most of the striped reddish and white rocks seen in the Painted Desert consist of the Petrified Forest Member. Within the Petrified Forest Member is the Black Forest bed, a fluvially reworked volcanic tuff that contains abundant petrified logs (Riggs et al., 2003; Martz and Parker, 2010). The highest stratigraphic member of the Chinle Formation within the park is the Owl Rock Member. The Owl Rock Member contains distinctive purple-gray paleosol at its base, overlain by several ledge-forming carbonate and paleosol beds, possibly representing lacustrine deposition (Parker et al., 2013). We will not visit any outcrops of the Owl Rock Member on this trip, though it can be seen at a distance in the Painted Desert from Stops 2.4 and 2.5.

In some northern locations within the park, and visited at Stops 2.4 and 2.5 (Fig. 3), strata of the Upper Triassic Chinle Formation are unconformably overlain by Neogene mudstones and lamprophyric and nephelinitic lavas of the Bidahochi Formation (Ort et al., 1998; Marsh et al., 2018). Pillow-like structures in the Bidahochi volcanic rocks suggest subaqueous eruptions or flows in a freshwater lake. These eruptions are part of the Hopi Buttes volcanic field, also visible to the northwest of the park as several conical peaks and flat-topped buttes and mesas (Parker et al., 2013).

The Colorado Plateau is thought to have been lifted to its present high elevation during the Late Cretaceous to Paleogene Laramide orogeny and subsequent rollback of the shallowly subducting Farallon slab (Humphreys et al., 2003). A transition in the late Paleogene Period from compressional to extensional tectonics, related to a change from convergent to transform motion at the outboard plate boundary (Atwater, 1970) and gravitational collapse of overthickened crust (e.g., Dickinson, 2002), led to crustal extension, subsidence, and listric normal faulting that formed the "basin-and-range" topography of southern Arizona and environs: alternating fault-bounded rocky ranges and sand-and-gravel-filled basins. Paleozoic and Mesozoic strata were largely eroded from many parts of southern and western Arizona. In contrast, the crust of northern Arizona was little affected, and remained thick and relatively undeformed, with only gentle folding at wavelengths of tens of kilometers across expansive regions like PEFO (Fig. 4). This produced the physiography of modern Arizona, which is typically subdivided into three provinces (Fig. 1): the high-elevation, low-relief Colorado Plateau (where PEFO is located); the low-elevation Basin and Range (where Phoenix is located); and the intervening, rugged Transition Zone, which incorporates geomorphic features of both adjoining provinces.

## ROAD LOG

### Day 1: Phoenix Area

On our drive from Phoenix to Holbrook (the closest town to PEFO), we will traverse all three of the physiographic provinces of Arizona: the Basin and Range, Transition Zone, and the Colorado Plateau (Fig. 1). We will climb from an elevation of 1086 ft

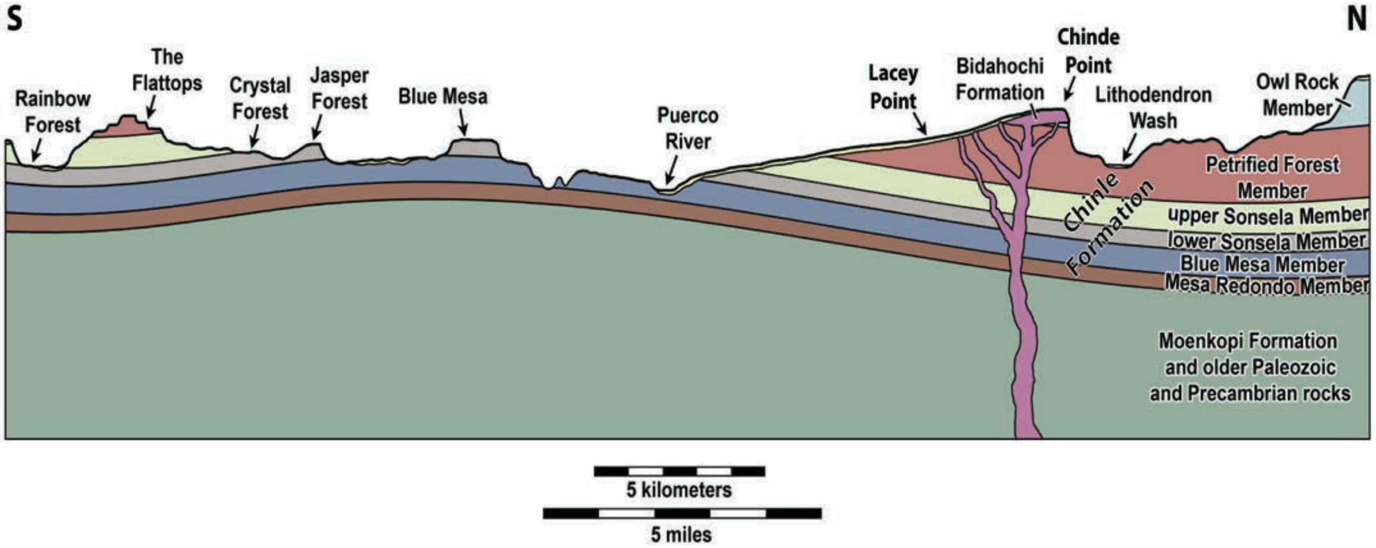

Figure 4. Generalized cross section from south to north through Petrified Forest National Park, adapted from Martz et al. (2012). The Moenkopi Formation at the base is overlain by the Chinle Formation (members listed at the right side, with individual colors), with the younger volcanic Bidahochi Formation shown as intruding the other formations and overlying them at Chinde Point.

(330 m) above sea level (a.s.l.) in Phoenix to 7700 ft (2350 m) a.s.l. on the Mogollon Rim (the topographic edge of the Colorado Plateau), and then descend to 5082 ft (1550 m) a.s.l. in Holbrook, which is situated in the valley of the Little Colorado River. We begin our trip in the arid Sonoran Desert, the warmest and lushest of North American deserts, characterized by saguaro and other cacti, legume trees such as the palo verde, and creosote bush. We continue upward into piñon-and-juniper woodlands and then into ponderosa pine forests on the Mogollon Rim; and end in the semi-arid grasslands (steppe) of the Colorado Plateau. Because of this physiographic and ecological diversity, Arizona is sometimes described as “many states in one.” It is certainly far more than the stereotypical flat, sandy, barren desert that many first-time visitors expect!

Underlying the varied topography and ecology of our first-day route is an equally complex and fascinating geology that encompasses Paleoproterozoic metamorphic and granitic basement, Mesoproterozoic–Neoproterozoic rift-basin sediments and sills, Paleozoic marine and continental sedimentary strata, and late Cenozoic volcanic rocks (mostly basalts) and basin-fill sediments. To help you interpret the geology you will observe along the drive and situate it in time and space, we recommend that you have a *Geologic Highway Map of Arizona* (Kamilli and Richard, 1998) open in front of you as a complement to this road log.

We depart downtown Phoenix on eastbound I-10 and State Route (SR) 202 freeways, following the floodplain of the Río Salado (Salt River) between the Phoenix Mountains and Camelback Mountain to the north, and the South Mountains (identifiable by the “forest” of tall antennae at its summit) to the south. The South Mountains are a metamorphic core complex, formed by extension and lateral shear between the middle and upper crust along a shallow northeast-dipping detachment fault between 25 and 20 Ma (Reynolds, 1985). The detachment fault extends into the subsurface to the north of the mountains, and is thus underneath us as we travel east. The South Mountains are formed on mylonitized Paleoproterozoic gneissic basement (**Xm** on the *Geologic Highway Map of Arizona*) and Oligocene–Miocene granitic plutons (**Tg**), both rock units of the lower plate (i.e., underlying the detachment fault). Rocks of the upper plate (above the subsurface detachment fault) include Proterozoic granites (**YXg**) and Neogene mudstones, sedimentary breccias, and volcanic rocks (**Tsm** and **Tb**). These were translated north-northeastward along the detachment fault, and are now exposed as the tops of southward-tilted fault blocks that protrude above the valley floor as Camelback Mountain and the Papago Buttes to the north of the SR 202 freeway; and Hayden Butte to the south, directly across Tempe Town Lake (a reservoir impounded behind a dam on the Río Salado). Sun Devil Stadium on the Arizona State University (ASU) campus in Tempe, visible from the freeway, was constructed in a saddle on Hayden Butte.

East (upstream) of the Papago and Hayden Buttes, the Río Salado floodplain is wider, and SR 202 closely parallels the river channel. Several scattered aggregate operations mine gravel and sand (**Q**) from the active channel and strath terraces on either side.

We leave SR 202 at **Exit 13** for SR 87, Country Club Road, and **turn north**, crossing the Río Salado into the *Salt River Pima* (*Akimel O’odham*) *and Maricopa* (*Piipaash*) *Indian Community.* At the intersection of SR 87 with McDowell Road just north of the river, the **Day 1 road log** begins. Some of the information in this road log for the segment from here to the base of the Mogollon Rim (ca. mile 90) is paraphrased from a previous road log published in Burt and Péwé (1978, p. 143–150).

### *Day 1: Road Log*

| *Cum. mileage* | *Desc.* |
|---|---|
| 0.0 | Intersection of SR 87 and McDowell Road. SR 87 was long known as the Beeline Highway because it enabled Valley of the Sun residents to “make a beeline” for the cool high country above Payson. In 1996, it was renamed the Duthie-Martin Highway in honor of two Arizona Department of Public Safety officers who lost their lives while on duty along the highway. |
| 0.8 | We are traveling on the second highest terrace of the Río Salado, the Mesa terrace (Burt and Péwé, 1978). The broad floodplain of the Río Salado and gradual slope of its terraces enabled construction of ~125 miles of canals valley-wide by the Hohokam people, ancestral to the contemporary O’odham, from the tenth through thirteenth centuries C.E. Today, 131 miles of irrigation canals (many along the original Hohokam alignments) and ~1000 miles of laterals and ditches are operated by the community-based Salt River Project utility. |
| 6 | SR 87 crosses the Arizona Canal, an irrigation system that draws water from the Río Salado 3.6 miles to the east at the Granite Reef diversion dam, completed in 1908. |
| 7.5 | Directly ahead is Red Mountain (*S-wegĭ Do’ag* in the O’odham language and *Wi:kawatha* in the Yavapai language), a fault-bounded horst. Paleoproterozoic quartz monzonite (**YXg** on the *Geologic Highway Map of Arizona* [Kamilli and Richard, 1998]) forms the base of the mountain and the surrounding subdued hills. This is overlain by a thick southwest-dipping sequence of deep-red Neogene landslide breccias (**Tsm**) formed on high-relief topography near the start of regional extension. These breccias are equivalent to those that form the Papago Buttes and the “head” of Camelback Mountain (Camel Head Formation) seen at the start of the trip. The upper part of Red Mountain consists of Neogene basalt lavas and dacite tuffs (**Tsv**) associated with the voluminous Goldfield-Superstition volcanic field (ca. 20.5 Ma to ca. 17 Ma; Ferguson and Trapp, 2001; see also below) to the east and southeast. |

9 Roadcuts in the Red Mountain landslide breccias (**Tsm**). Note the angular, grayish-white, poorly sorted granitic clasts in the deep-red matrix.

10 SR 87 crosses the aqueduct of the Central Arizona Project (CAP), completed in 1993 at a cost of ~US$4 billion, and operated by the Central Arizona Water Conservation District. The CAP system transports water from the Colorado River at Lake Havasu across 336 miles (540 km) of desert to Phoenix and thence to Tucson, lifting it more than 2900 ft (880 m) in elevation from one end of the system to the other. According to the Central Arizona Water Conservation District (2019), only ~1% of the annual flow is lost to evaporation. The CAP illustrates a principle oft-cited in the Southwest that "water flows uphill toward money" (Reisner, 1986, p. 12).

11 Junction of SR 87 with Shea Boulevard, and the boundary between the Salt River Pima-Maricopa Indian Community and the Fort McDowell Yavapai Nation. A short distance ahead, the highway begins to descend to the floodplain of the Verde River, a major tributary of the Río Salado.

13 Last traffic signal for the next 62 miles (100 km), and crossing of the Verde River. The Verde is a perennial stream supplied mostly by springs and small streams draining the Mogollon Rim to the northwest (Arizona Department of Water Resources, 2014). Across the river, a prominent high terrace is visible, built of Neogene valley-fill sediments reworked by the Verde River (Pope, 1974) and held up by a thick zone of calcrete and silcrete (Burt and Péwé, 1978).

14 SR 87 winds through Neogene valley-fill deposits (**Tsy**), many of which exhibit well-developed beds and zones of caliche (calcrete). Here, we are passing from the Basin and Range Province into the Transition Zone.

15 Leave the Fort McDowell Yavapai Nation and enter the Tonto National Forest, the largest National Forest in Arizona and the fifth largest in the entire United States.

15.6 Ahead on the right is Stewart Mountain, a mass of Proterozoic quartz monzonite (**YXg**) surrounded by Neogene valley fill (**Tsy**).

17 The iconic Four Peaks in the Mazatzal Mountains are now prominent. Etymology of the name *Mazatzal* is uncertain, but some have suggested it derives from the Nahuatl language. The Four Peaks are a large roof pendant of Paleoproterozoic metamorphic rocks (metavolcanic and metasedimentary rocks **Xm** and purple Mazatzal Peak quartzite **Xq**) among three different Paleoproterozoic and Mesoproterozoic granitic plutons (**YXg**). The metamorphic rocks are folded into a doubly plunging syncline with a roughly NE-SW axis (Skotnicki, 2000). The northernmost summit of the four, Brown's Peak, is highest at 7,659 feet (2,335 m) a.s.l., and also the highest peak in Maricopa County. Amethyst has been mined here, and the Four Peaks are depicted on Arizona license plates.

22 Interchange with the Bush Highway, which leads south to a chain of reservoirs along the Río Salado that are very popular for picnicking, floating, and boating during the hot summer months.

24 Ahead the Mazatzal Mountains and Four Peaks are beautifully presented, and back toward the southeast is a comparably spectacular panorama of the Goldfield and Superstition Mountains. These are formed of volcanic rocks (**Tsv**) from a paroxysm of mostly felsic volcanism that extended from ca. 20.5 Ma to ca. 17 Ma (McIntosh and Ferguson, 1998; Ferguson and Trapp, 2001; Fodor and Johnson, 2016). The eruptive sequence encompassed early-stage dacite domes and flows, a major caldera eruption with a widespread rhyodacite ash-flow tuff at 18.6 Ma, post-caldera domes and basalt flows, and resurgence that hoisted the boxy mountain visible on the horizon. The pinnacle to the left is Weaver's Needle, an erosional remnant of the 18.6 Ma ash-flow tuff.

25 To the left is Sugarloaf Mountain, capped by Neogene basalt flows.

26 Spheroidally weathered Paleoproterozoic granite (**YXg**) is particularly well exposed in this area. The weathering, both mechanical and chemical, begins in the subsurface along intersecting sets of joints in the granite and proceeds inward, resulting in rounded, largely unweathered spheroidal blocks surrounded by grus (Burt and Péwé, 1978). As the granite becomes exposed, the grus erodes away, leaving scattered granite spheroids that continue to weather, but more slowly.

27 Roadcut through a Neogene (?) basalt dike (**Tb**) in the Paleoproterozoic granite (**YXg**).

30 SR 87 crosses Mesquite Creek. Just ahead are good exposures of Neogene basin-fill sediments (**Tsy**) overlain by even younger basalt flows (**Tb**). These flows also locally overlie Paleoproterozoic basement (**Xm** and **YXg**). An examination of the *Geologic Highway Map of Arizona* reveals that these four map units—two old and two young—are the predominant rocks exposed across the Transition Zone province. Paleozoic and Mesozoic strata are largely absent.

33 SR 87 crosses Pine Creek. Saguaro cacti abound in this vicinity.

36 A normal fault exposed in the roadcut on the left, just past the sharp rightward curve in the highway, places Neogene basin-fill (**Tsy**) against Proterozoic granite (**YXg**).

40 SR 87 crosses Sycamore Creek in the tiny community of Sunflower. Sycamore Creek continues to the west and empties into the Verde River. To the northwest, Mount Ord (7128 ft or 2170 m a.s.l.), is the prominent, rounded mountain with communications towers at the summit, formed of Paleoproterozoic schist (**Xm**) intruded by Paleoproterozoic pyroxenite and quartz monzonite (**YXg**; Burt and Péwé, 1978).

41 SR 87 crosses Kitty Joe Creek and cuts through a sequence of Neogene basalt flows (**Tb**). As we climb gradually toward a saddle beneath Mount Ord, we are passing from the upper Sonoran Desert into piñon-and-juniper woodlands. Ahead, note the retaining walls futilely designed to resemble basalt outcrops.

42 SR 87 crosses Whiskey Springs.

44 SR 87 re-crosses Kitty Joe Creek.

45 Saddle at the top of the uphill grade, elevation 4565 ft (1390 m) a.s.l., at the intersection with a road that leads up to the summit of Mount Ord. A prominent knob of Neogene basalt (**Tb**) is visible north of the highway. We cross from Maricopa County into Gila County, and descend on a 7% grade toward the canyon of Slate Creek through the eastern Mazatzal Mountains.

46 North of milepost 224, note the engineering controls on the slopes visible along both sides of the highway. An old two-lane segment of SR 87 between Sunflower and Slate Creek was realigned as a four-lane highway farther east and completed in 2003. This stretch of the new highway near the bottom of the downhill grade was built through an area with identified paleo-landslide activity (Conway, 1995). Repeated earth movements occurred here through the winter of 2007–2008, culminating in a landslide on 21 March 2008 that forced the closure of SR 87 for six days (Diaz et al., 2008). Mitigation work continued here for many months, and thus far there have been no subsequent road-closing landslides.

47.2 Enter the canyon of Slate Creek, a passage through the eastern Mazatzal Mountains, at an elevation of 3500 ft (1070 m) a.s.l. Strongly foliated basement rocks exposed in this deep cut are Paleoproterozoic slates, phyllites, and schists (**Xm**) of the metavolcanic upper Alder Group (1710–1700 Ma; Karlstrom and Bowring, 1988), intruded regionally by granites (**YXg**) at 1640–1630 Ma and again at ca. 1400 Ma (Karlstrom and Bowring, 1988). The metamorphic rocks contain talc and chlorite, and cinnabar (mercury ore) was mined locally from mineralized veins in the slates and phyllites from the 1920s to the 1950s (Faick, 1958). Higher up on ridges to the northeast, resistant Proterozoic quartz veins can be seen protruding above the subdued slopes on the softer slates and phyllites. Slate Creek Canyon exposes part of an east-northeast–striking shear zone that juxtaposes two crustal blocks (or terranes) crunched together during assembly of the continental lithosphere (Karlstrom and Bowring, 1988). The last few saguaro cacti that we will see on this trip are scattered on the south-facing slopes above the canyon.

52.5 Visible on the left, a normal fault juxtaposes Neogene basin-fill deposits (**Tsy**) and Paleoproterozoic metamorphic basement (**Xm**).

53 The highway climbs through a roadcut in metavolcanic rocks (**Xm**) of the Paleoproterozoic Red Rock Group (ca. 1700 Ma), which postdate the Alder Group rocks seen farther back in the canyon. In the distance on the right, the Tonto Basin can be seen. Although the word “tonto” means “silly” or “foolish” in Spanish, this toponym is actually thought to have been derived from an Apache word, *Koun’nde,* meaning “wild, rough people” and referring to the *Dilzhe’e* Tonto Apache indigenous to the area (White Mountain Apache Tribe, 1998).

54 To the west, a resistant bed of Paleoproterozoic Mazatzal Group quartzite (**Xq**) is well exposed along the flank of the Mazatzal Mountains. Sedimentation, deformation, and plutonism in the Mazatzal Mountains records the effects of two Proterozoic orogenies: the Mazatzal (ca. 1650 Ma) and Picuris (ca. 1450 Ma); the relative intensity of the two orogenic events is debated (e.g., Mako et al., 2015; Daniel et al., 2013).

55 Directly north, light-colored Neogene lacustrine limestone and siltstone beds (**Tsy**) of the Payson Basin are visible. The Payson Basin is one of a chain of fault-bounded basins that trend northwest to southeast along the boundary between the Transition Zone and the Colorado Plateau. The Tonto Basin lies immediately to the southeast and the Verde Basin (more commonly known as Verde Valley) is the next basin to the northwest. These basins formed by extension and block faulting in the Miocene, approximately coeval with Basin and Range extension to the south and southwest (e.g., McKee and Anderson, 1971). These Neogene basins underwent complex histories of sedimentation and incision reflecting interactions of tectonics, volcanism, and climate (e.g., Pedersen, 1969; House and Pearthree, 1993; Ott et al., 2018). At various intervals in the Miocene and Pliocene, the basins contained freshwater or saline lakes. SR 87 cuts through the lacustrine beds of the Payson Basin (**Tsy**) over the next several miles.

57 Junction of SR 87 and SR 188, which follows the Payson and Tonto Basins southeast past Roosevelt Lake to the copper-mining area of Globe-Miami.

| | |
|---|---|
| 58 | SR 87 crosses Deer Creek. The Sierra Ancha, visible on the horizon to the east and southeast, are formed on extensive exposures of Mesoproterozoic rift-basin sedimentary rocks (**Ys**), basalts, and diabase dikes and sills (**Yd**) of the Apache Group. |
| 60 | SR 87 crosses Rye Creek and enters the small community of Rye. |
| 62 | Past Rye, SR 87 climbs a ridge that separates two canyons; the northbound and southbound lanes of the highway are widely separated in this area. |
| 69 | Roadcut through altered Mesoproterozoic diabase (**Yd**), ca. 1100 Ma. |
| 70 | Around milepost 250, note the roadcuts through the Paleoproterozoic Payson Granite (**YXg**), ca. 1700 Ma. The Mogollon Rim, a great regional scarp in Paleozoic strata that forms the topographic edge of the Colorado Plateau, is prominent across the northern horizon. A smaller scarp to the south, the Diamond Rim, runs roughly parallel to it. |
| 71 | Leave the Tonto National Forest and enter the town of Payson, elevation 4890 ft (1490 m) a.s.l. Beds of the Cambrian Tapeats Sandstone (Cambrian and Mississippian rocks are grouped together on the *Geologic Highway Map of Arizona* as **MC**) lying unconformably on the Paleoproterozoic granite below are visible on the left. This is thus a small section of the "Great Unconformity" exposed locally below the Mogollon Rim and dramatically in Grand Canyon. Tapeats sands were deposited across the region in the Sauk transgression; the rock unit was recently dated at 508 Ma by detrital-zircon analysis (Karlstrom et al., 2018).<br>The reservation of the Tonto Apache (*Dilzhe'e* Apache) Tribe, the smallest in Arizona at 85 acres but boasting the impressive Mazatzal Hotel and Casino, is on the right. The Tonto Apaches refer to Payson as *Tegosuk*, "Place of the Yellow Water." |
| 73 | Junction of SR 87 and SR 260. **Turn right** on SR 260 toward Heber and Snowflake. The Safeway supermarket is located on the right side of SR 260. |

### *Stop 1.1: Safeway Supermarket/Starbucks Coffee Shop in Payson*
### *SR 260 (34.23994N, 111.831770W)*

Brief break for wheelchair-accessible restrooms, beverages, and snacks. Note that this is the last accessible bathroom stop until we reach Holbrook.

| *Cum. mileage* | *Desc.* |
|---|---|
| 74 | In roadcuts for the next several miles, SR 260 passes through heavily weathered outcrops of Paleoproterozoic granitic rocks (**YXg**). |
| 76 | Enter the community of Star Valley. |
| 77 | Pass an abandoned granite quarrying and crushing operation on the right as SR 260 leaves Star Valley and re-enters the Tonto National Forest. |
| 81 | SR 260 expands to a four-lane highway and passes through deep roadcuts in Paleoproterozoic granite (**YXg**). Along this segment, piñon-and-juniper woodlands grade into increasingly dense forests of tall Ponderosa pines. |
| 82 | SR 260 crosses Preacher Canyon on a high bridge. On the left and just below the Diamond Rim escarpment, Cambrian Tapeats Sandstone (**MC**) forms prominent outcrops. |
| 83 | Enter Little Green Valley. From here to the base of the Mogollon Rim, SR 260 passes through exposures of a thick Paleozoic sedimentary section encompassing the Cambrian Tapeats Sandstone, Devonian Martin Formation, Mississippian Redwall Limestone, Pennsylvanian Naco Formation, and Pennsylvanian–Permian Supai Group. The first three units are grouped together on the *Geologic Highway Map of Arizona* as **MC** and the last two as **PIP**. Note that it is difficult to keep abreast of stratigraphic order from the outcrops and roadcuts, as the units have been offset by numerous faults in this area. |
| 84 | On the left, Proterozoic quartz veins stand out in relief above more subdued terrain in Paleoproterozoic basement. |
| 86 | Straight ahead is a view of Promontory Point, a dramatic salient on the Mogollon Rim. The rim is capped by a resistant buff-white layer of Permian Coconino Sandstone (**P**), an eolian unit considered to mark the perimeter of the Colorado Plateau in this region. |
| 87 | SR 260 crosses Thompson Draw. |
| 87.5 | Roadcuts in the Mississippian Redwall Limestone (**MC**). Although this unit forms a substantial cliff in Grand Canyon, in this vicinity it has been heavily karstified in many localities, leaving deep-red *terra rosa* and characteristic black-and-white chert nodules and stringers. |
| 88 | The paleontological site on the right is a well-known fossil locality in shaly limestone and sandy mudstone beds of the lower member of the Pennsylvanian Naco Formation (**PIP**). Crinoid stem fragments and plates, bryozoans, gastropods, pelecypods, productid and spiriferid brachiopods, and conularids (Beus and Brew, 1978) abound at this locality, which unfortunately is not wheelchair-accessible. |
| 89 | SR 260 crosses Tonto Creek; intersection with Tonto Creek Road. Roadcuts ahead are in red Pennsylvanian–Permian Supai Group and gray-yellow-maroon Pennsylvanian Naco Formation (both **PIP**). |
| 90 | Junction of SR 260 with Camp Tontozona Road, which leads south to Tonto Creek Camp, owned by |

| | |
|---|---|
| | Arizona State University. Roadcuts in Devonian Martin Formation (**MC**). |
| 90.4 | SR 260 crosses Doubtful Canyon; roadcuts are in Martin Formation and karstified Redwall Limestone. |
| 93 | Junction of SR 260 and the west end of a loop road through the community of Christopher Creek. Roadcuts here are in limestones and mudstones of the middle member of the Naco Formation. |
| 93.2 | SR 260 crosses Christopher Creek. Roadcuts are in the Martin Formation and Redwall Limestone. |
| 95 | Junction of SR 260 and the east end of the Christopher Creek loop road. |
| 96 | SR 260 crosses Sharp Creek. Ahead are low roadcuts in the Naco Formation. |
| 97 | Start of the upgrade to the top of the Mogollon Rim. SR 260 here is in the Naco Formation. |
| 98 | Contact between the Pennsylvanian Naco Formation (predominantly marine limestones and marginal-marine mudstones) and the deep-red rocks of the Pennsylvanian–Permian Supai Group (both **Pℙ**), which consists of interbedded limestones, mudstones, conglomerates, and sandstones, and records an interval of fluctuating sea levels along a coastal-plain environment that gradually became more arid (Blakey and Middleton, 2012). |
| 100 | SR 260 climbs through the gray Fort Apache Limestone, a carbonate bed in the upper Supai Group strata. Some geologists consider all of the massive red sandstone beds in the uppermost Supai Group on the Mogollon Rim to be a different Upper Permian unit: the Schnebly Hill Formation, with the Fort Apache Limestone as a member therein (e.g., Blakey, 1990). |
| 101 | Contact between the red Supai Group (or Schnebly Hill Formation) and the overlying, buff-yellow Permian Coconino Sandstone (**P**), an eolian rock unit deposited in an extensive erg. The Coconino Sandstone caps the Mogollon Rim, and we will be driving atop it for the next 35 miles. |
| 102 | Top of the Mogollon Rim; enter Coconino County and the Apache-Sitgreaves National Forest. Just ahead, **turn right** into the U.S. Forest Service Mogollon Rim Visitor Center. |

### *Stop 1.2: Mogollon Rim Visitor Center*
### *SR 260, Elevation 7500 ft a.s.l. (34.30165N, 110.89643W)*

The Mogollon Rim Visitor Center is perched on the topographic southern edge of the Colorado Plateau. The back deck offers a commanding view of the rugged Transition Zone country that we have just traversed.

Accessibility

Although the front door appears to be wheelchair accessible, the visitor center was closed during the time of our scouting visit. *According to the center's site, the center is primarily open during the summer season.* The deck at the rear of the visitor center is wheelchair accessible. The restroom facility in the parking lot is likely inaccessible for wheelchairs.

Objectives

1. Introduction of field-trip participants;
2. Review of Arizona geology and geography: what we've seen and what's ahead; and
3. Question-and-answer session.

| *Cum. mileage* | *Desc.* |
|---|---|
| 104 | Prominent eolian cross-beds are visible in roadcuts in the Coconino Sandstone here and for the next few miles. We are in the thick of the mighty Ponderosa-pine forests that cover the Mogollon Rim country. |
| 107 | As we pass the entrance to the Canyon Point Campground in the Apache-Sitgreaves National Forest, we are at an elevation of 7700 ft (2350 m) a.s.l.: the highest point on our field-trip route. |
| 108 | Enter the vacationers' community of Forest Lakes. |
| 111 | Enter Navajo County. |
| 112 | SR 260 crosses Wildcat Canyon (not much of a canyon). At various places ahead and on the right side of the highway, burn scars from the devastating anthropogenic Rodeo-Chediski wildfire of 2002, the second-largest in Arizona history, are still visible. |
| 123 | At milepost 303, enter the community of Heber-Overgaard. |
| 124 | Roadcuts in the Coconino Sandstone on the left and right sides of the highway. |
| 126 | Junction of SR 260 and SR 277. **Turn left** on SR 277 for Snowflake and Holbrook and pass through the outskirts of Heber-Overgaard. |
| 130 | Roadcut in the Coconino Sandstone, showing especially vibrant color banding along contacts and joints (due perhaps to reactions with groundwater). |
| 133 | Junction of SR 277 and SR 377. **Turn left** on SR 377 for Holbrook. Here we turn northeast, away from the Mogollon Rim, and begin a slow descent to the valley of the Little Colorado River where Holbrook is located. We also soon pass from Ponderosa-pine forest back into lower-elevation piñon-and-juniper woodlands. |
| 137 | Wind turbines of the Dry Lake Wind Power Project are visible in the distance ahead atop a ridge. This was the first commercial-scale wind farm in Arizona, and it has a capacity of 127 megawatts. |
| 142 | Descend into the basin of Dry Lake, filled with Quaternary sediments (**Q** on the *Geologic Highway Map of Arizona*). |
| 146 | SR 377 crosses Pulp Mill Wash. The pulp mill referred to is the now closed plant to the southeast (visible in the distance) in the town of Snowflake. |

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| 147 | Red beds of the Lower Triassic Moenkopi (named for a Hopi community and pronounced *MOON-copy*) Formation (**Trm** on the *Geologic Highway Map of Arizona*) are exposed in the bluffs on the north edge of the Dry Lake basin. This is our first encounter with Mesozoic strata, which have been eroded far back from the edge of the Mogollon Rim. |
| 150 | Entrance to the Dry Lake Wind Power Project on the right. Ahead, on the distant horizon, the pinnacles and lava-capped mesas and buttes of the Neogene Hopi Buttes volcanic field on the Navajo and Hopi Nations are visible. The *Diné* or Navajo name for this volcanic field is *Tsézhin bii’* (*TSEH-zhin-bee*), meaning “among the black rocks.” |
| 162 | The high stacks of the coal-fired, 1020-megawatt Cholla Power Plant, operated by Arizona Public Service, are visible to the north-northeast. Coal for the plant is transported by rail from the San Juan Basin in New Mexico. As is the case for many similar plants across the West, this plant is scheduled either to be converted to a different fuel or closed no later than 2023. |
| 165 | Ahead and to the right, pastel-colored, low-relief sandstone and mudstone beds of the Moqui Member overlie ledgy, darker-red sandstone beds of the Wupatki Member, both in the Moenkopi Formation (**Trm**). |
| 166 | SR 377 crosses the Apache Railroad tracks and enters the crossroads community of Holbrook, seat of Navajo County, elevation 5082 ft (1550 m) a.s.l. Just ahead, behind the Navajo County government buildings, low buttes are held up by thick beds of the Shinarump Conglomerate, basal member of the Chinle Formation (**Trc**). The Chinle Formation is named for the Navajo Nation community of Chinle, or *Ch’ínílí,* meaning “stream flowing out of a canyon” and referring to the location of the community at the mouth of Canyon de Chelly, 95 miles (153 km) north-northeast of here. The Chinle Formation is the principal rock unit exposed in PEFO, and it has endowed the park with beautiful petrified wood and other fossils, as well as its striking badlands topography and red Painted Desert. |
| 167 | Junction of SR 377 and SR 77. **Turn left** on SR 77 toward Holbrook. |
| 168.6 | Junction of SR 77 and U.S. Highway 180 east to Petrified Forest. |

### *Stop 1.3: Jim Gray’s Petrified Wood Company, Holbrook Junction of SR 77 and U.S. 180 (34.89011N, 110.16029W)*

A fun stop to whet the appetite for the field trip to the National Park. Don’t spend all of your money!

Note that any petrified wood or other geological samples purchased here should be kept wrapped, accompanied by the receipt, and preferably in your stowed luggage, while you are in the National Park tomorrow.

Accessibility

Wheelchair-accessible restrooms, tactile samples of fossils and minerals.

*After the stop, proceed north on SR 77 across the Little Colorado River bridge into downtown Holbrook.*

### *Stop 1.4: Holbrook Lodging in Holbrook (34.93264N, 110.13602W)*

Overnight lodging in Holbrook. Dinner in town. Please take some time to preview the field guide in preparation for the Day 2 field-trip stops in PEFO.

Accessibility

Best Western Arizonian Inn has two wheelchair-accessible rooms. All other hotels/motels in Holbrook have one wheelchair-accessible room, some with roll-in showers.

***End of Day 1 road log.***

## Day 2: Road Log

***Please note that the collection of archaeological artifacts, fossils, rocks, or other natural history objects without an active research and collection permit is illegal at Petrified Forest National Park. Please avoid collecting samples or specimens of any kind from anywhere in the park.***

| *Cum. mileage* | *Desc.* |
|---|---|
| 0.0 | Depart Holbrook hotel and drive south on SR 77 to intersection with U.S. 180 (~3.5 miles; 34.89169N, 110.16179W). |
| 3.5 | **Turn left** (east) on U.S. 180 to Petrified Forest Road (17.5 miles; 34.81083N, 109.89082W). From Holbrook the road passes through the Moenkopi Formation and the underlying Coconino Sandstone; the Kaibab Formation was not deposited this far east. The best exposure of the Coconino is at the Little Colorado River Bridge (at 6.6 miles), where it can be seen in the canyon walls. Approximately 100 meters to the north, the original 1913 one-lane highway bridge can be seen on the old road alignment. At mile 15.7, we pass another old road alignment, bypassed in 1972 that used to bring Highway 180 through the southern portion of the National Park. We will visit outcrops along this alignment at our first stop in the park. Around mile 16, we start to see our first good outcrops of the lower part of the Upper Triassic Chinle Formation. |
| 21.0 | **Turn left** (north) on Petrified Forest Road to south entrance of PEFO (0.7 miles; 34.79438N, |

109.89082W). See Figure 3 for stop locations within PEFO. Note that the rock shops at this intersection are privately owned and not associated with the National Park Service.

21.7 **Turn left** (west) on private park road to Rainbow Canyon (0.7 miles). ***Note:*** This road is closed to vehicle traffic, although registered field trips and hikers can access the area.

### *Stop 2.1: Rainbow Canyon*
### *Old National Trails Highway, Subsequently Old Rt. 180 (34.82067N, 109.87796W)*

This private park road to Rainbow Canyon is the old U.S. 180, and prior to that it was the old National Trails Highway. Abundant petrified logs and smaller fragments of petrified wood that are apparent near the road (Fig. 5) are from the Rainbow Forest bed (stratigraphically equivalent to the Jasper Forest bed) of the Sonsela Member of the Chinle Formation. Local buttes consist of the Rainbow Forest bed at base, overlain by the Jim Camp Wash beds, and capped by the Martha's Butte beds. See Figure 2 for the stratigraphic position within the Chinle Formation of these beds and the rocks at each subsequent stop.

Accessibility

Accessibility at this stop is limited. The private roadway is paved, although there is limited access off of the road, with scrub brush and unconsolidated ground material. However, outcrops are clearly visible and hand samples can be gathered to show those with limited off-road mobility. *Notice:* Be sure to replace any temporarily gathered hand samples nearest to the locations they are collected from.

Objectives

1. Overview of the field-trip design, focusing on small groups of mixed-ability participants that will work on focused exercises at several stops throughout the field trip.
2. Overview of approaches to accommodating accessibility challenges in the field.
3. Introduction to the geology of PEFO (see "Geological Background" section above).

Questions to Consider

1. Where do these petrified logs fit within the stratigraphy of the nearby butte to the west?

Figure 5. View of butte in Rainbow Canyon (Stop 2.1). Petrified wood fragments are apparent in the foreground. The prominent butte is composed of the Jasper Forest bed at the base, overlain by Jim Camp Wash beds, and capped by Martha's Butte beds. Two of the authors for scale.

2. Examine the cobbles lying on the ground. Characterize the variety of the clasts. What is the relative abundance of the different clast types?

| *Cum. mileage* | *Desc.* |
|---|---|
| 22.4 | Return east along the private park road to Petrified Forest Road (0.7 miles). |
| 23.1 | **Turn left** (north) on Petrified Forest Road and drive 5.8 miles to the Crystal Forest parking area. |

### *Stop 2.2: Crystal Forest and the Battleship Petrified Forest Road (34.86383N, 109.79196W)*

A paved loop trail (the "Crystal Forest Trail") winds through a large deposit of petrified logs of the Jasper Forest bed. The trail facilitates close examination of many logs; note that the northern fork of the trail is more topographically challenging than the southern fork. The approximate halfway point of the loop trail (called the "Rest/Reflection Platform" on the interpretative sign) has the "Twin Sisters" logs (Fig. 6A), which are noticeably lighter in color than the majority of petrified log specimens.

The prominent butte west of the park road is Battleship Rock (Fig. 6B), consisting of the Lot's Wife beds at the base, overlain by protruding petrified logs of the Jasper Forest bed, which is overlain by the Jim Camp Wash beds near the top.

Accessibility

The Crystal Forest trail loop is continuously paved (0.8 miles total distance), beginning and ending in the parking lot. Following the path to the right path has less gradient variability than the path to the left. The halfway point from both directions is an uncovered concrete platform for rest and reflection, and a great view of the surrounding environment. No restrooms are available here.

Objectives

1. Break into small mixed-ability groups to work on focused exercises. One group will work on each of the following exercises:
   a. Assemble a bed-level stratigraphic column of Battleship Rock, as viewed from the parking area.
   b. Travel along the Crystal Forest trail loop, and choose one or two locations at which to describe in detail the morphology and mineralogy of one or more petrified logs.
2. Reassemble at the covered picnic area (0.1 miles from the Crystal Forest trailhead), where each small group will briefly report on the results of their chosen exercise, to be followed by questions and a general group discussion.

Questions to Consider

1. How accurately can the bed-by-bed stratigraphy of Battleship Rock be correlated with the overall stratigraphic section (Fig. 2) of PEFO?
2. What relict tree structures are apparent in the petrified logs? What has caused the spectacular coloration in the logs? What variations can you see among the logs? What evidence of depositional environment is apparent in the logs and in the surrounding sedimentary strata? What caused the fractures and breaks in the logs?

| *Cum. mileage* | *Desc.* |
|---|---|
| 28.9 | **Turn left** out of the parking area and return south on Petrified Forest Road to the Southern PEFO Visitor's Center (5.7 miles). |

### *Stop 2.3A: Southern PEFO Visitor's Center Petrified Forest Road (34.81518W, 109.86565W)*

The Southern PEFO Visitor's Center is our lunch and restroom stop. We will not conduct specific exercises here, but there are several interesting sites to visit if you have time. These include:

1. The Rainbow Forest Museum (ca. 1934), which has interesting exhibits on park geology and history. A park gift shop is located here.
2. The Giant Logs loop trail, which features petrified logs of the Rainbow Forest bed, including the iconic Old Faithful Log.
   a. Optional activity: Find out who named this the Old Faithful Log, and why.
   b. Be sure to check out the photo in the visitor center of Albert and Elsa Einstein next to Old Faithful Log; lots of history here!
   c. Note that all logs in the park are conifers, and some logs in the area reach 197 ft (60 m) in length (Parker et al., 2013).

Accessibility

Accessible restrooms and museum exhibits. The Giant Logs loop trail is partially paved and moderately accessible due to high-angle grading. Nearly all steps have been recently removed along this trail to improve accessibility. However, some parts of the trail may be closed due to reconstruction as the park continues to improve public access.

| *Cum. mileage* | *Desc.* |
|---|---|
| 34.6 | **Turn left** and drive back north on Petrified Forest Road (cross over I-40) to the old Route 66 pullout (20.1 miles). |

### *Optional Stop 2.3B: Historic Route 66 Petrified Forest Road (35.05134N, 109.80518W)*

The rusted 1928 Studebaker President Eight car (Flintstones-style, with no floorboards) and the wireless telephone poles mark the location where historic U.S. Highway 66, immortalized in songwriter Bobby Troup's 1946 song "Route 66" passed through the park is the only National Park to contain a section of historic Route 66.

| *Cum. mileage* | *Desc.* |
|---|---|
| 54.7 | Continue north on Petrified Forest Road to the Lacey Point parking lot (0.9 miles). |

Figure 6. Prominent features at Stop 2.2. (A) One of the “Twin Sisters” logs, located at the approximate midpoint of the Crystal Forest trail; red pen (circled) for scale. (B) Battleship Rock, which consists of strata from Lot’s Wife beds (base), the Jasper Forest bed (the logs that protrude like battleship “guns”), and the Jim Camp Wash beds at the top.

### *Stop 2.4: Lacey Point*
### *Petrified Forest Road (35.06304N, 109.80263W)*

This overlook of a stratigraphic section includes the Petrified Forest Member of the Chinle Formation and the overlying Neogene Bidahochi Formation (Fig. 7). From here we are looking out over the broad expanse of the Painted Desert (extending northwest to Cameron, Arizona).

Accessibility

Fully accessible overlook, although the railing may impede visibility for wheelchair users. No restrooms here.

Objectives

1. Work in small mixed-ability groups to assemble a bed-level stratigraphic column of the butte in the immediate foreground, NNW of the parking area. Be sure to note any significant breaks in the stratigraphic sequence.
2. Discuss the environmental settings during the formation of the rocks in the section.

Questions to Consider

1. Where does the bed-by-bed stratigraphy of the butte at Lacey Point fit into the general stratigraphy of PEFO?
2. Is the stratigraphic sequence generally conformable throughout the section? Discuss why or why not.

| *Cum. mileage* | *Desc.* |
|---|---|
| 55.6 | Continue north on Petrified Forest Rd. to the **left turn** to Chinde Point (2.4 miles). |

### *Stop 2.5: Chinde Point*
### *Petrified Forest Road (35.08634N, 109.79602W)*

Excellent overlook of the Painted Desert (to the north) from the north side of the parking area. Note that this overlook is atop the volcanic rocks of the Bidahochi Formation (Fig. 8). These volcanic rocks are classified as sodic lamprophyres or nephelinites, rather than basalts, and are part of the Hopi Buttes volcanic field (Ort et al., 1998). Pillow-like structures are apparent in the cliffs below the overlook. However, scrambling down to these exposures is rather treacherous and is ***not*** recommended. We suggest that the volcanic rocks are better examined from the covered picnic tables on the south side of the parking area.

Figure 7. View of the stratigraphy of the Painted Desert from the Lacey Point pullout (Stop 2.4). The prominent red strata are the Petrified Forest Member. The dark-colored resistant cap of the distant butte consists of volcanic rocks of the Neogene Bidahochi Formation.

<u>Accessibility</u>

Be sure to locate the tactile dinosaur bone attached to the wayside interpretive sign near the overlook at this location. The lack of pavement here presents a moderate mobility challenge to view rock exposures on the cliff face below the overlook. Access to the volcanic wall face to the south of the parking area is also moderately challenging, although the picnic shelters sit on ground-level concrete pads within 20 ft (6 m) of the outcrop, providing both an excellent view and respite from the sun. Restrooms here have space for wheelchair access, although hand rails and bars are not present to aid with transfer.

<u>Objectives</u>

1. Work in small mixed-ability groups to examine and characterize the volcanic rocks of the Bidahochi Formation. Be sure to note apparent smaller- and larger-scale structures and discuss how they may have formed.
2. Discuss the environmental setting during the eruption and solidification of the volcanic rocks, as well as any later alteration of the rocks.

Figure 8. View to the north from Chinde Point (Stop 2.5). Pillow-like structures in the volcanic rocks of the Bidahochi Formation are apparent in the lower foreground, with brightly colored strata of the Painted Desert in the distance.

<u>Questions to Consider</u>

1. Are the spherical structures in the volcanic rocks pillows? Why or why not?
2. Is any columnar jointing apparent here?
3. Where in the volcanic succession did the breccia come from? What is the nature of the matrix between the clasts?

| *Cum. mileage* | *Desc.* |
|---|---|
| 58.0 | Return to the main road and **turn left** on Petrified Forest Road. Drive to the Painted Desert Visitor Complex (2.5 miles). |

***Stop 2.6: Painted Desert Visitor Complex***
***Petrified Forest Road (35.06569N, 109.78180W)***

Restroom stop only. Please avoid spending too much time at the gift shop, as we have a long drive back to Phoenix.

| *Cum. mileage* | *Desc.* |
|---|---|
| 60.5 | Drive (south) to PEFO north entrance (0.5 miles). |
| 61.0 | **Turn right,** take the onramp to I-40 west, and drive to Holbrook (~24.5 miles). |
| 85.5 | Drive south to Payson via SR 77, SR 377, SR 277, and SR 260 (97.5 miles). |

***Stop 2.7: Payson, Arizona, Dinner Stop***
***(34.21984N, 111.33080W)***

| *Cum. mileage* | *Desc.* |
|---|---|
| 183 | Return to Phoenix via SR 260, SR 87, SR 202. |
| 363 | Arrive back in Phoenix. End of trip! |

***End of Day 2 road log.***

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