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THE GEOARCHAEOLOGICAL LANDSCAPE OF WALLACE TANK PUEBLO (AZ Q:1:199 (ASM)), PETRIFIED FOREST NATIONAL PARK, ARIZONA: REHABILITATING THE DAMAGED CULTURAL LANDSCAPE OF A PUEBLO IV VILLAGE

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ABSTRACT — Petrified Forest National Park (PEFO) is a unique landscape of physical beauty and paleontological treasures. Known for its ancient fossils, petrified wood, and awe-inspiring vistas, it is also well-known in the archaeological community as having some of the earliest villages on the southern Colorado Plateau. Additionally, it is home to a few large late precontact pueblos (Pueblo IV period: ~1275-1400 CE) that were once part of an extensive regional network of communities where people and goods moved across the landscape. Wallace Tank Pueblo is the largest Pueblo IV period village within the Park. This once thriving 600-room pueblo was home to the ancestors of the Zuni, Hopi, and other descendant communities. Over time the physical features of the village were damaged by historic ranching activities and natural erosion. It is now a scoured and degraded landscape where the once sustaining natural spring is not even identifiable. Because of the uniqueness of this village within the Petrified Forest environment consultations between the Park and descendant communities should consider management plans that will re-establish a spring-fed wetlands. Such a plan would not only focus on preservation of the cultural features, but also on the health of the environment and that of the descendants who maintain an emotional and spiritual connection to this ancestral village.

Keywords: Geoarchaeology; Pueblo IV; Rehabilitation; Descendant Communities; Traditional Knowledge.

INTRODUCTION

Wallace Tank Pueblo (AZ Q:1:199 (ASM)) is a 600-room Pueblo IV period village in the southeast corner of Petrified Forest National Park (Fig. 1). Occupied between about 1275 and 1400 CE, the site was part of an interconnected regional network of communities and trade extending throughout the Little Colorado River, Puerco River, and Zuni River watersheds. The site was on private ranchlands prior to being transferred to the Park in 2016. Taking advantage of raised roomblocks arcing around the natural spring, ranchers excavated a large cattle tank into the center of the site in the late 1800s (Fig. 2). For the next 100 years additional tanks, uncontrolled excavations, and road maintenance further damaged the site. Monsoon rains in the Fall of 2010 caused the main tank to fill and overflow, eroding parts of the site and exposing a previously unknown roomblock. Park

personnel expressed concerns about the erosion that occurred and future erosional risks. Therefore, a damage assessment to the site was undertaken, including recommendations for reducing future impacts. The background information below provides the geoarchaeological context for reducing the potential impacts of further erosion. A further argument exists for re- establishing the original spring-fed wetlands at the center of the site, not only for the stability of the physical, built environment, but also for the spiritual and emotional health of descendant communities.

Previous Work

Leslie Spier was the first to record Wallace Tank Pueblo when he visited it in 1917 (Spier, 1918). At that time, however, Spier conflated Wallace Tank Pueblo with another site 4 km to the east, Stone Axe Pueblo, previously recorded by Hough (1903). The misconception that they were the same site contributed to quite a bit of confusion until Gilpin et al., (2003) demonstrated they were separate sites. Spier inferred that "the tank here probably occupies the position of an aboriginal reservoir", the first observation that there must have been an active spring and source of fresh water for the community (Spier, 1918). He also noted "the ruin had been partially dug into, while the cemetery to the east has been plundered." He made a random collection of the abundant surface pottery. A large collection of pots purchased by the American Museum of Natural History, and thought to be from Wallace Tank Pueblo, was inventoried as part of the Puerco Ridge Archaeological Survey Project (Schachner et al., 2016). Below is a brief overview of work done and the cultural context of Wallace Tank Pueblo.

Several researchers from various institutions briefly visited the site over the following decades, making observations, collecting pottery, and drawing maps. No systematic archaeological excavations have been undertaken to date. Lyndon Hargrave from the Museum of Northern Arizona (MNA) made a pottery collection in 1929, and MNA archaeologists produced the first sketch map of the site in 1933. Also, in 1933 H.P. Mera recorded the site for the Laboratory of Anthropology at the Museum of New Mexico (Mera, 1934). In 1953 Richard Woodbury from Columbia University updated the 1933 MNA map by better delineating the tank locations and artifact concentrations. More recent investigations were conducted for the early phases of the proposed Park expansion. The Western Archaeological Conservation Center produced a more detailed map in 1988, as did Gilpin et al., (2003). Schachner et al., (2016) surveyed the landscape around Wallace Tank, producing a detailed total station map, and placing the Pueblo IV village in a broader cultural landscape context (Fig.2). For a comprehensive discussion of previous research, cultural history, and survey results, see Schachner et al., (2016).

Wallace Tank Pueblo

The Pueblo IV period (1275–1400 CE) in the Petrified Forest region is characterized by a population aggregation into a few large villages (60 to 600 rooms) including Wallace Tank, Puerco, and Stone Axe pueblos, and smaller sites like Black Axe Pueblo (40 to 60 rooms). The earlier Pueblo II (900–1150 CE) and Pueblo III periods (1150–1275 CE) are marked by smaller sites and more dispersed settlements, with little evidence of aggregation.

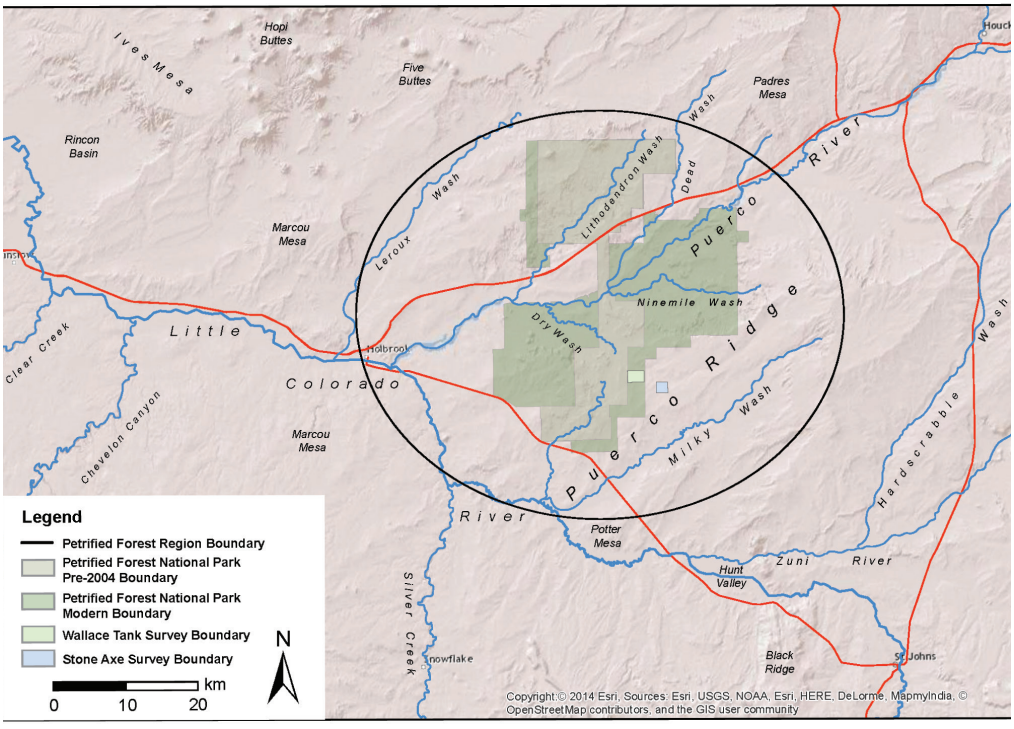


FIGURE 1. Wallace Tank Pueblo is within the Wallace Tank Survey Boundary (from Schachner et al., 2016). Map by R. J. Sinensky.

Pueblo IV sites in the region are situated along major rivers such as the Puerco and Little Colorado rivers, near springs and seeps (e.g. Wallace Tank Pueblo), and with access to a variety of resources and trade routes (e.g. Nuvakwewtaqa in Chavez Pass, southwest of Winslow). The advantageous location of villages, extensive petroglyphs, and similar pottery assemblages at the various sites indicates there were diverse social ties, active population movement, and extensive trading of goods across a broad interregional network of large, economically integrated sites during the late 13th through early 15th centuries.

Details of the original layout of Wallace Tank Pueblo have been obscured by the historic and modern impacts, such as tank construction and uncontrolled excavations into the existing architecture. Nonetheless, much of the architecture remains visible, and inferences can be made from the sequences of earlier maps of the site. There are five roomblocks, identified as Roomblocks A, B, C, D, and E, as well as several plazas. Roomblocks A and B, which may originally have been one large complex, are oriented around a large plaza to the southeast. Roomblocks B, C, and E are at least in part oriented around the probable location of a spring. Roomblock D is situated on the edge of a modern arroyo, although it is possible (probable?) the arroyo was not present during the period of occupation. The approximate distance from the southwest edge of Roomblock A to the northeast edge of Roomblock D is 360 meters, and from the southeast edge of Roomblock D

to the northwest edge of Roomblock B is 200 meters. A rough estimate of site size is therefore 72,000 m2 (7.2 hectares). Roomblocks are constructed of sandstone, quarried from about 2 kilometers to the east, and adobe bricks, likely manufactured from local materials. The use of both materials occurs at a few Pueblo IV villages in the region (e.g., Homol'ovi I, Fourmile). Based on the amount of rubble, thickness of walls, and depth of looting pits, some of the roomblocks were likely multistoried.

Modern disturbances to the Village. — Wallace Tank (the cattle tank) was in use as early as 1912 because it is plotted on the USGS Petrified Forest 15-minute map of that date. As noted by Spier in 1917, the cattle tank and looting had already damaged the architecture and spring/reservoir. Over the ensuing decades, continued expansion of the tank, extensive mechanized looting, road maintenance, and bulldozing of the landscape further deteriorated the cultural and scientific integrity of the site. A large berm was constructed by bulldozing a deep basin and pushing that mix of cultural and natural materials up against the northeast extension of Roomblock B and portions of Roomblock D, connecting them to form the northern edge of the main cattle tank. This berm effectively dammed the

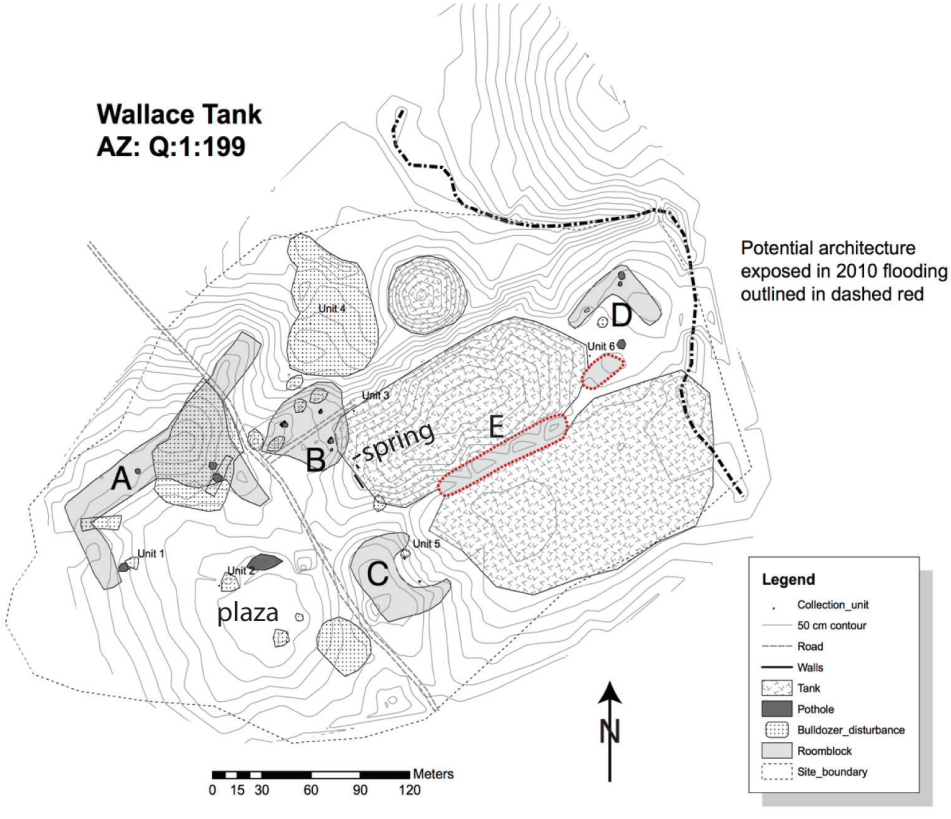


FIGURE 2. Total station map of Wallace Tank Pueblo, a 600-room Pueblo IV (1275-1400 CE) village in Petrified Forest National Park (from Schachner et al., 2016; Fig. 2, p.9). This map highlights ground disturbance from bulldozer and pot hunting activity. Areas outlined in red dashed lines are architecture exposed by the 2010 flood.

drainage where the spring and associated wetlands were located.

Geoarchaeological Setting

Understanding the geomorphic processes involved in the development of landforms provides the underlying framework for assessing archaeological site formation processes. The concept of geoarchaeological landscape is used because it places geomorphic aspects of the cultural landscape at the forefront. The initial selection of the site by the Pueblo IV period inhabitants, site layout, and site formation processes active before, during, and after occupation are used to gain insights into erosion, deposition, stability, and preservation of the site within the physical landscape context. Results gleaned from geoarchaeological investigations inform the broader themes related to cultural landscapes, including plans for preservation and rehabilitation. Below is a summary of the geology of the project area, followed by a discussion of the landscape properties and processes encountered by the Pueblo IV period inhabitants.

Petrified Forest is known for the multi-colored sedimentary rock layers of the Triassic Chinle Formation, and the petrified logs, paleontological finds, and stark, undulating, badland topography that characterizes its erosional landscape (KellerLynn, 2010; Martz et al., 2012). The approximately 200-million-year-old clay and sandstone layers were deposited by a broad, extensive river system derived from the Appalachian Mountains, some 1000 miles away. Additional marine, eolian, and alluvial deposits during the subsequent 200 million years (Jurassic, Cretaceous, and Tertiary periods) covered the region with thousands of meters of rock strata. Uplift of the Colorado Plateau during the Tertiary Period, removed much of those layers, forming the badlands we see today. Between about 9 and 4 million years ago, numerous volcanoes erupted. The Hopi Buttes volcanic field produced several lava flows interbedded with lake deposits. Portions of those lava flows remain as erosional mesas and buttes in the area including Headquarters Mesa, Pilot Rock, and culturally significant Black Knoll. The lake and lava flows are called the Bidahochi Formation, after the nearby town.

Wallace Tank Pueblo is on the southern end of northeasterly oriented Puerco Ridge, a landform measuring 40 km long by 10 km wide. Puerco Ridge was created by downcutting on its northwest side by the Puerco River and on the southeast side by Milky Wash, both of which flow southwestward into the Little Colorado River. That alluvially transported sediment is then blown back out of the Little Colorado River to the northeast by the prevailing winds, accumulating on Puerco Ridge, where it forms a series of long, linear dunes, stretching towards the northeast. The oldest dunes date to the late Pleistocene, between about 200 thousand years ago (ka) and 75 ka (Ellwein, et al., 1997). Linear dunes in the North Rim section of Petrified Forest were reactivated during the latest Pleistocene, between about 18 ka and 13 ka, and again during the Holocene, between about 8 to 2 ka (Fig. 3a; Schott, 2019). The youngest dunes and sand sheets are thought to be less than 1000 years old. It is reasonable to assume that the same eolian process occurred at the same time on the southern edge of Puerco Ridge, in the vicinity of Wallace Tank Pueblo (Fig. 3b).

Wallace Tank Pueblo sits on isolated knolls, interdunal swales, and short

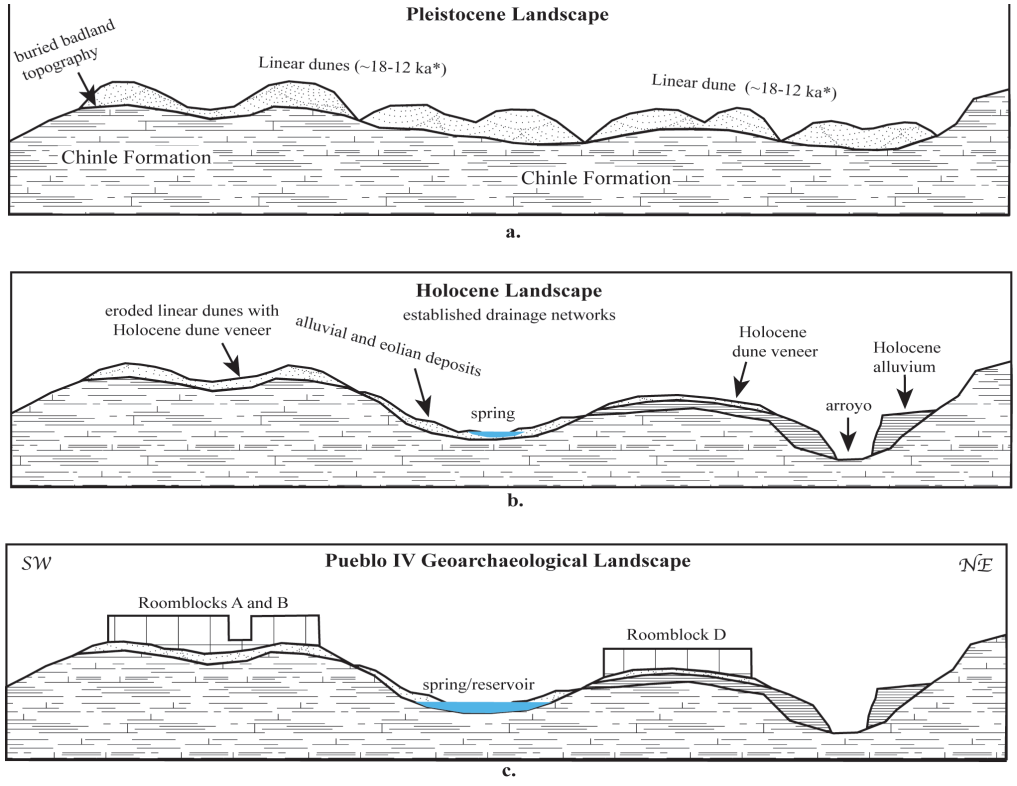


FIGURE 3. Schematic cross sections showing landscape changes from Pleistocene (a), pre-Pueblo IV landscape, (b), and the Pueblo IV Period (c). Approximate distance across the figure is 500 meters.

ridges that are the barely recognizable remnants of those linear dunes (Fig. 3c). After about 13 ka alluvial erosion along tributaries to the Puerco and Little Colorado rivers began to erode the dune fields atop Puerco Ridge. Milky Wash cuts deep into the southeast side of Puerco Ridge, and Dry Wash cuts into the west and northwest edges. The entire southern third of Puerco Ridge is nearly separated from the main Puerco Ridge because of erosion along the East Fork of Dry Wash and its tributaries. Wallace Tank Pueblo is along a minor tributary to an unnamed drainage that then flows into the East Fork of Dry Wash. Dry Wash is a tributary to the Puerco River. Except for Puerco Pueblo, which is on the Puerco River, the other previously mentioned Pueblo IV sites in Petrified Forest are along Dry Wash and its tributaries.

METHODS

A Digital Surface Model (DSM) of Wallace Tank was generated using aerial photogrammetry with centimeter spatial resolution. Contours were produced with the ArcGIS Pro Spatial Analyst toolbox Contour function. The DSM was filled for minor depressions using the Spatial Analyst toolbox Fill tool. Flow Direction (D8) and Flow Accumulation functions

were applied to the filled DSM to produce flow paths. The surrounding watersheds of Wallace Tank are derived from a digital elevation model (DEM) obtained from the Shuttle Radar Topography Mission (SRTM) with 1 arc-second (~30m) resolution. Watersheds were calculated from a flow direction raster and selected points along flow paths. This was completed with the Watershed tool within ArcGIS Pro Spatial Analyst toolbox. Watersheds and flow paths are derived from the DEM using the ArcGIS Pro Hydrology toolset within the Spatial Analyst toolbox.

RESULTS

The Petrified Forest landscape is essentially an ancient badlands with portions of it buried by a relatively thin layer of reworked windblown sand of Pleistocene and Holocene ages. Subsequent erosion of the linear dunes and drainage development produced the landscape mosaic for the Pueblo IV period occupation. The early inhabitants of Wallace Tank Pueblo encountered an undulating landscape dominated by low mounds, the eroded dunes, and a patchy and mobile layer of eolian sediments that provided an important substrate for agriculture (Schott, 2019). Shallow bedrock keeps water near the surface. The early occupants had a variety of landscape settings for crop production and sources of fresh water, utilizing the spring-fed wetlands for plant and animal resource procurement.

The Spring

We are not certain if the spring in the center of the site had been modified to form a reservoir, as Spier assumed, or a masonry constructed well, as suggested by the intriguing presence of rock alignments in the area where the spring might have been located (Fig. 4).Although it may have simply been a modified seep, robust, formally constructed masonry wells are important sources of fresh water at Zuni, Hopi, and elsewhere. Whatever the case, freshwater springs are the lifeblood of Puebloan society, revered in their origin stories, and protected for use by the entire community. Based on Spier's original inferences, results of archaeological survey, and traditional knowledge of Zuni tribal members (Maren Hopkins, pers.comm.) there had to have been a reliable, available, and sacred freshwater spring at this location, otherwise the 600-room Pueblo IV village could not have existed.

The following discussion is based on GIS modeling of the modern landscape (Fig. 5). The ancient landscape may have had subtle variations in drainage directions that differ from what is seen in the modern landscape. The extensive dune field south of the pueblo is the catchment area for the ancient seep or spring. A drainage on the western side of the site (orange outline) directs flow to the immediate west, bypassing the site today, although it is possible that this drainage once flowed closer to the spring area. A small catchment (0.58 km2) outlined in yellow captures surface flow and directs it towards the small depression southeast of Roomblock A's plaza. The largest catchment (7.61 km2) outlined in green directs flow to the spring. The smallest catchment (0.56 km2) directs flow into the arroyo. It is probable that this arroyo was not incised during occupation of the site. If that is true, then water in this catchment flowed towards the spring during occupation. The heavily disturbed



FIGURE 4. Possible remains of ancestral Puebloan reservoir in low spot between Roomblocks B and C (from Schachner et al., 2016, fig. 17).

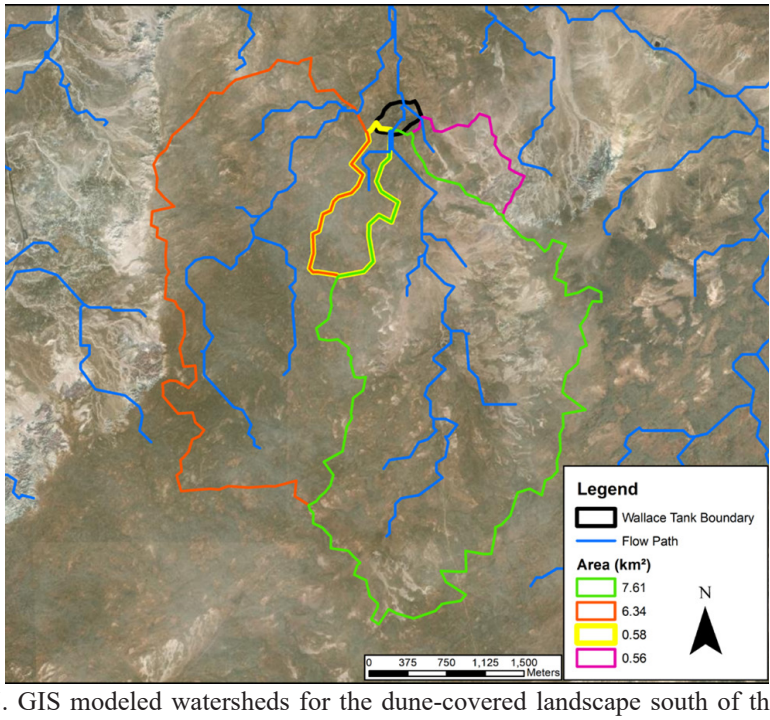


FIGURE 5. GIS modeled watersheds for the dune-covered landscape south of the site. This area accumulates precipitation that flows as both surface and subsurface water toward the site.

and altered landscape, with three cattle tanks, berms, roads, and bulldozed waste piles, makes definitive determination of surface and shallow groundwater flow direction difficult to accurately model.

During rainfall events water infiltrates into the sandy dune deposits, and percolates downward to the contact between the dunes and underlying Chinle Formation, which is essentially impermeable. Water then flows down the buried slope towards the pueblo where shallow bedrock forces water to the surface, creating a natural spring termed a "seep in dune hollow" by Hack (1942). If rainfall rates are high enough, overland flow will also occur.

The Cattle Tanks

Construction of the initial cattle tank scoured out the ancient spring, arguably the heart of the pueblo village. Damage to the site's architecture continued for the next 100 years. Over time three tanks were carved into the site to trap surface and shallow groundwater for cattle.

The large oval southern tank that functioned as the settling pond was originally oriented in a northeast-to-southwest direction (Fig. 6). Google Earth imagery indicates that sometime between 2007 and 2010 its northern berm was re-positioned to a more east-west orientation to better capture surface flow from the east (Fig. 7). The southern tank which held water in the Fall of 2012, presently measures about 175 m x 60 m (Fig. 8). The approximate area of all three cattle tanks (2.1 hectares) takes up nearly one-third of the area of the ancestral village (7.2 hectares).

The main tank is the largest and deepest of the tanks. It is oval with a 150 m long axis-oriented northeast- to-southwest, and a shorter northwest-to-southeast axis measuring 60 m. The tank could hold about 50,000 m³ of water, equivalent to 20 Olympic-sized pools. Continued enlargements of the cattle tank included scouring deeper into the underlying Chinle Formation clays, and piling that material, mixed with cultural materials, higher on the dam, or northern berm. The construction of this berm effectively connected the northeast extension of Roomblock B with that of Roomblock D. Therefore, Roomblocks B and D frame the northwest side of the main tank, and Roomblocks C and E frame its south and southeast sides. The northern tank is circular with a diameter of about 50 m and served as an overflow catchment when the main tank reached a high enough level to flow through buried culverts.

The 2010 Flood

Several monsoon storms moved through PEFO during the Fall of 2010, eventually filling Wallace Tank to overflowing. The overtopping of the northern berm of the main tank produced three deep channel cuts, that must have progressed rapidly, leading to the emptying of the tank, and destruction of the northern, circular tank (Fig. 8). Flood deposits from erosion of the berm spread out in a broad debris fan between the berm and the arroyo to the north of the site (Fig. 9). The debris fan includes abundant artifacts because the berm consisted of bulldozed cultural and natural materials (Fig. 10a). There is a small erosional headcut where the debris fan empties into the arroyo north of the site. Headcut erosion could become a threat to roomblocks as it progresses upslope towards the tanks. the berm and the arroyo to the north of the site (Fig. 9). The debris an includes abundant artifacts because the berm consisted of bulldozed cultural and natural materials (Fig. 10a).

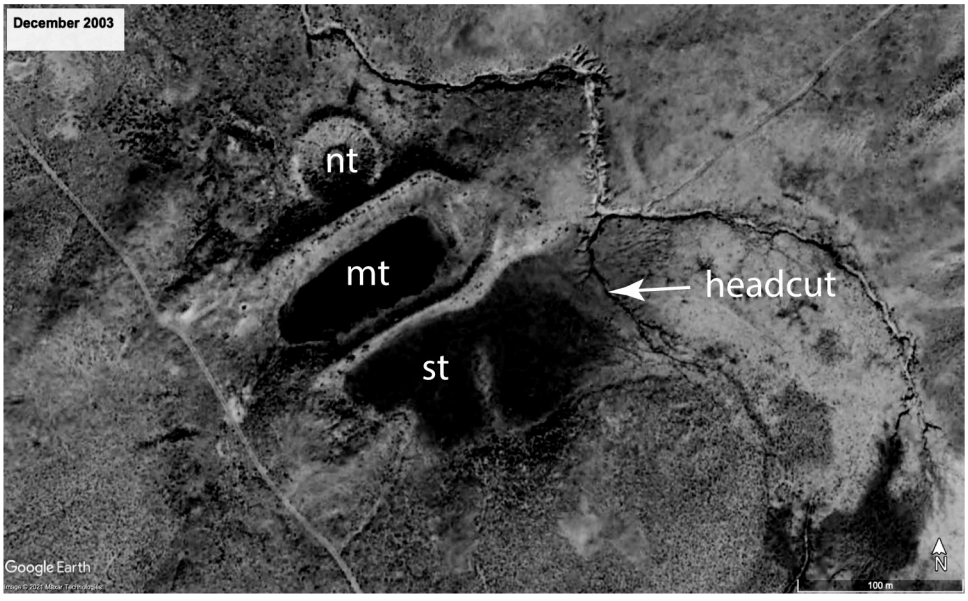


FIGURE 6. Google Earth image from December 2003. Of note are the circular northern tank (**nt**), oval main tank (**mt**), and southern tank (**st**) sharing its northern berm with the main tank. Headcutting from the arroyo captures surface waters and bypasses the tanks.

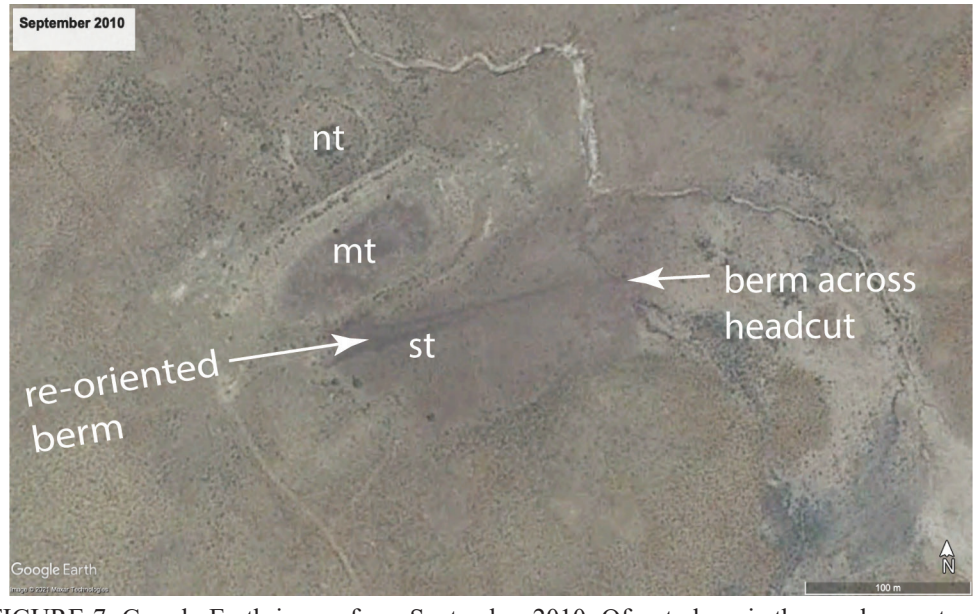


FIGURE 7. Google Earth image from September 2010. Of note here is the newly constructed northern berm of the southern tank that was emplaced between 2008 and 2010. This new east-to-west orientation is an attempt to capture overland flow, and perhaps to slow down the headcutting. Also, there is a discrepancy in the timing of the flood and breaching of the main tank. Ranchers notified PEFO personnel in mid-August 2010 that the tank had been breached, but this image from September shows no damage, suggesting the time stamp for the Google Earth image is incorrect.

There is a small erosional headcut where the debris fan empties into the arroyo north of the site. Headcut erosion could become a threat to roomblocks as it progresses upslope towards the tanks.

The three deep cuts in the northern berm are numbered, from west to east as 1, 2, and 3 (Fig. 10b). Of the three deep cuts into the berm, the western one is closest to Roomblock B but does not directly impact it. The base of the western cut is about 2 meters above the level of the main tank floor, so water entering the tank today will not flow out the west cut. The middle cut (#2), being the widest and deepest, is graded to the same level as the bottom of the tank. Water flowing into the main tank today flows through the middle cut. The eastern cut (#3) is close to Roomblock D. It is likely that construction of the berm negatively affected cultural deposits associated with Roomblock D, but no architectural elements were impacted by the 2010 flood.

In addition to erosion along the northern berm, the southern berm of the main tank was also affected by the 2010 rainfall event. The main tank filled to the top of the southern berm. When the water eroded the northern berm, the tank rapidly emptied causing slumping and rill erosion along the southern berm, exposing a previously unrecorded roomblock, Roomblock E. Apparently this roomblock was obscured by construction of the southern berm. Relatively undamaged masonry walls, adobe walls, and flagstone floors can be seen eroding from the berm. Parts of Roomblock E architecture were bulldozed during berm construction as can be seen with obviously pushed and tilted alignments. Because the newly



FIGURE 8. Google Earth image from October 2012. The re-orientation of the northern berm of the southern tank captured water from the eastern drainages, filling the southern tank with water. The three cuts in the north berm of the main tank (shown by arrows marked west-to-east are 1, 2, and 3) are clearly visible. Headcutting has also begun to proceed southward from the arroyo toward the middle cut (2) of the main tank. Also visible is erosion along the southern berm of the main tank, where previously unrecorded roomblock (dashed red in Figure 2) exposed by the flood is subject to erosion.

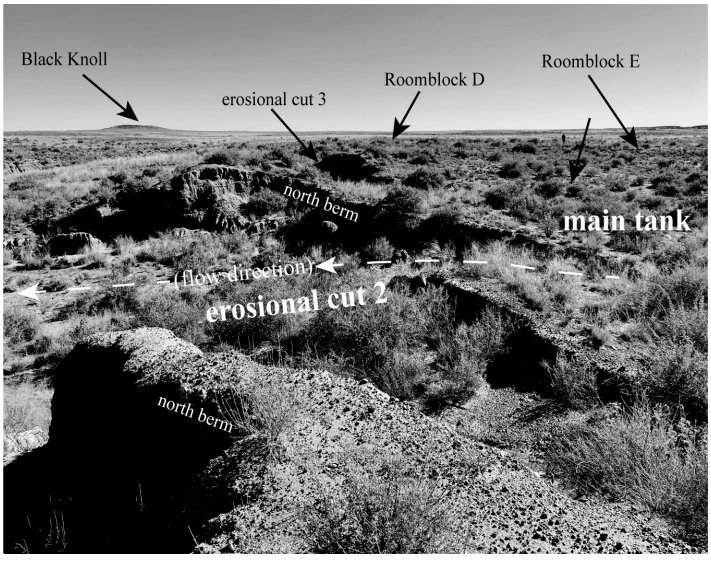


FIGURE 9. Erosional cut 2 (center of image) through the northern berm is now the outflow for the main tank. View to the northeast.

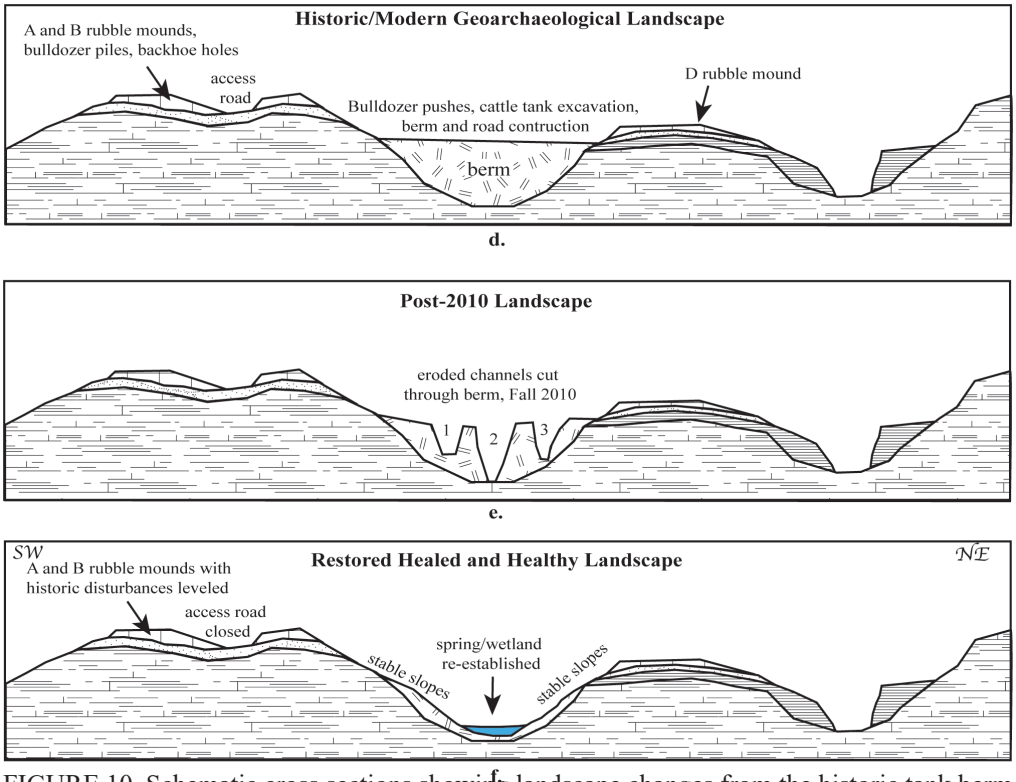


FIGURE 10. Schematic cross sections showing landscape changes from the historic tank berm (a), 2010 flood (b), and proposed restored landscape (c). Approximate distance across the figure is 500 meters.

exposed architecture is eroding out of thesouthern berm, this part of the site is threatened from continued rill erosion. Although decades of large-scale, uncontrolled excavations using heavy equipment occurred, significant intact cultural materials of important scientific and cultural value remain buried and preserved. It therefore seems important to design a plan of action to re-establish the spring-fed wetlands to as close to an original condition as possible (Fig. 10c).

Areas of the site at risk for continued erosion are (1) Roomblocks A, B, and C where the access road crosses the roomblocks; (2) Roomblock D where headcutting erosion from the knickpoint at the outlet (cuts #2 and 3) could eventually impact the architecture there; and (3) Roomblock E from continued rilling, particularly during rainfall episodes that cause the southern tank to fill and overtop (Fig. 11).

DISCUSSION

Using GIS modeling, archaeological survey, and total station mapping, we have evaluated the preservation and rehabilitation potential to avoid further deterioration of the site itself, and to restore the site's ancient ecosystem. The following questions help guide the discussion: (1) What should Wallace Tank Pueblo represent to the tribes, visitors, and the National Park Service (NPS)? (2) Should plans of action be aimed at preserving the present state, a Pueblo IV period village with nearly one third of its area taken up by cattle tanks?

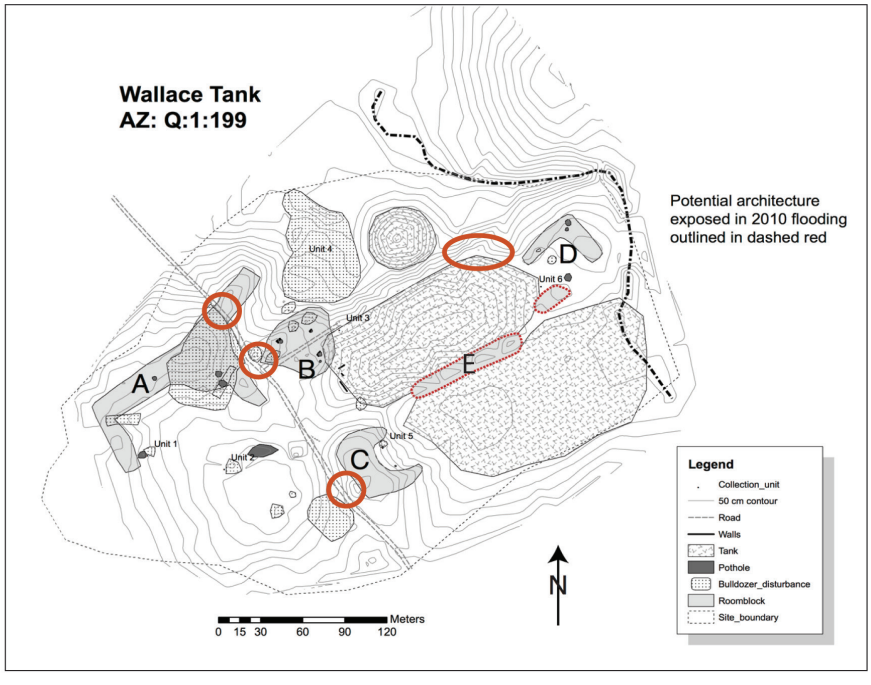


FIGURE 11. Total station map of Wallace Tank Pueblo showing areas of potentially highest risk of damage to architectural elements of the site, in both solid and dashed red outlines (modified from Schachner et al., 2016).

(3) Can the spring be transformed into a healthy cultural landscape with a spring-dominated ecosystem that could be a model for how ancestral sites can be rehabilitated in collaboration with descendant communities? and (4) How does Wallace Tank Pueblo fit into PEFOs broader mission? Answers to these questions can only be found through discussions with tribal representatives, NPS personnel, and other stakeholders. Nonetheless, we would suggest that this unique archaeological site should not be dominated and defined by cattle tanks and previous uncontrolled excavations. We instead suggest it should look as much like a "natural" setting as possible with a re-established spring/wetland/seep area capable of supporting plant resources, waterfowl, and animals. A place where the descendants of the people who lived here, and resource managers from the NPS, can feel satisfaction knowing the site is restored to a healthy cultural ecosystem.

The precise location of the Pueblo IV spring may not be known, but using ground penetrating radar, GIS modeling, and limited excavations, we might be able to estimate its location and target that area for spring restoration. Schachner et al., (2016) provide some guidance as to where the spring might have been located:

> *"To the south of the roomblock [Roomblock B], a few possible sandstone masonry wall alignments are visible along the edge of the former tank (see Fig. 4). These may be the remains of structures disturbed in tank construction or possibly remains of the ancient reservoir that was the tank's predecessor" (p.32). [And again]*
>
> *"The archaeological remains could be the part of a partially intact structure, possibly the ancient reservoir, or disturbed portions of a roomblock completely destroyed by tank construction and distant from their original location. Excavation would be required in this area to differentiate among these possibilities..." (p.37).*

Allen Haden, a spring and wetlands rehabilitation specialist in Flagstaff, Arizona visited the site to assess the potential for re-establishing the wetlands. Haden has successfully re-established springs on the Hopi Reservation, and elsewhere. His insights are summarized here (Haden, 2022):

> *"A 2D hydraulic model can be utilized to show current and proposed flow path, flooding depth velocity and shear stress using a detailed topographic map (derived from LiDAR). The grading design can be informed by this model to ensure that erosive forces are reduced throughout the site. A seepage model based on soil type can show the potential effects on water movement and gradient through the soils to help understand the potential for spring reemergence in the target area. Finally, an engineered site design can be developed and staked on the ground to ensure that disturbance to critical areas (cultural features) is avoided, and the design is implemented as precisely as*

possible. The goal of the design would be to remove as much of the berms and pond grading as possible, while promoting wide shallow flow across the site to minimize erosion and promote soil storage of runoff."

We have taken initial steps to better understand the water flow dynamics of Wallace Tank Pueblo. A digital surface model (DSM) showing the built environment (both ancestral Puebloan and historic) shows the main flow direction going through the large plaza and into the main tank, and other flow paths into the southern tank, which then flow into the main tank area (Fig. 12). Further analysis illustrates the higher elevations dunes where water is stored before flowing towards the spring. The lower elevation areas of the site, where water will contact the bedrock and emerge as springs, would then flow into the main tank and out the breach. Haden (2022) suggests re-grading the berms and basins to promote wide, shallow non-erosive flow and encouragement of soil water storage in the location where the cattle tanks are currently located (Fig. 13).

There are many varied attributes of an archaeological site, some of them tangible and others intangible. Geoarchaeological investigations at Wallace Tank Pueblo focused on the tangible – the built environment set into the modern physical landscape, and how the associated landforms have changed over time. Yet a significant part of an archaeological site remains inaccessible to geomorphic studies and archaeological data recovery. Below is an argument to go beyond simply addressing the erosional risks to cultural features, but to address the spiritual and emotion concerns of descendant communities. Input from tribal representatives, Park personnel, and ecosystem restoration experts will be critical.

Affiliated tribes consider all aspects of the cultural landscape as part of their living, interconnected world. Besides the houses, hearths, and artifacts, the crops, croplands, animals, springs, hills, mesas, rock outcrops, and distant features are also part of that world. Beyond those physical aspects of a site, the spirits of the ancestors persist. Descendant communities feel as strongly connected to the homes and water sources of their villages as they do to the spirits of the ancestors who remain there. A quote from Dongoske, 2020:229 summarizes this from a Zuni perspective:

"Federal agencies typically view Zuni ancestral sites simply as archaeological sites. Consequently, these agencies think that adverse effects to these properties are only related to the loss of archaeological information and materials. Zuni people, however, understand their ancestral sites as active living places because they are the eternal homes of the Zuni ancestors that maintain heritage connections and spiritual vitality essential for the successful continuation and flourishing of Zuni culture. These archaeological sites are an inheritance that the Zuni people received from their ancestors who lived, loved, sacrificed, and endured pain and suffering to pass on their knowledge as well as material

and embodied connections to this landscape as Zuni heritage. As such, contemporary Zuni people have a strong sense of stewardship to respect and honor their ongoing spiritual connection to their ancestors' spirits and to protect the eternal homes of their ancestors. Knowledge of their failure to protect the eternal homes of the ancestors creates deep psychological and emotional anguish for Zuni people."

While "mitigating" adverse effects to archaeological sites by focusing on inadvertent discoveries and built features, we need to consider with equal importance the health of the land, otherwise we are only addressing one obvious concern. The built environment cannot be separated from the land, which in turn cannot be separated from the ancestors who lived there and the descendants who are responsible for its upkeep.The following statement by Lyle Balenquah (2008:150) summarizes the interconnectedness, indeed, inseparable connectedness, of Hopi people and the land:

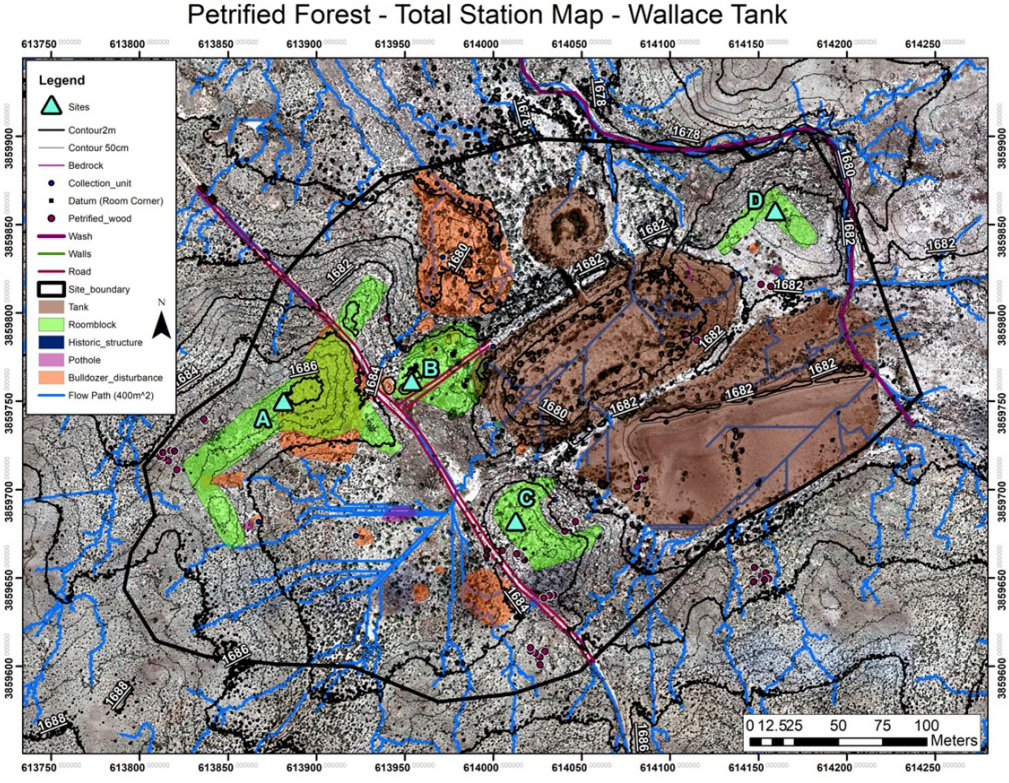


FIGURE 12. Map of Wallace Tank Pueblo showing relationships between roomblocks, tank, modern disturbances, topography, and drainage patterns. DSM modeling suggests most of the surface water enters the main tank from the southwest, between Roomblocks B and C. Other contributions are from the settling tank (southern tank) and from groundwater seeps.

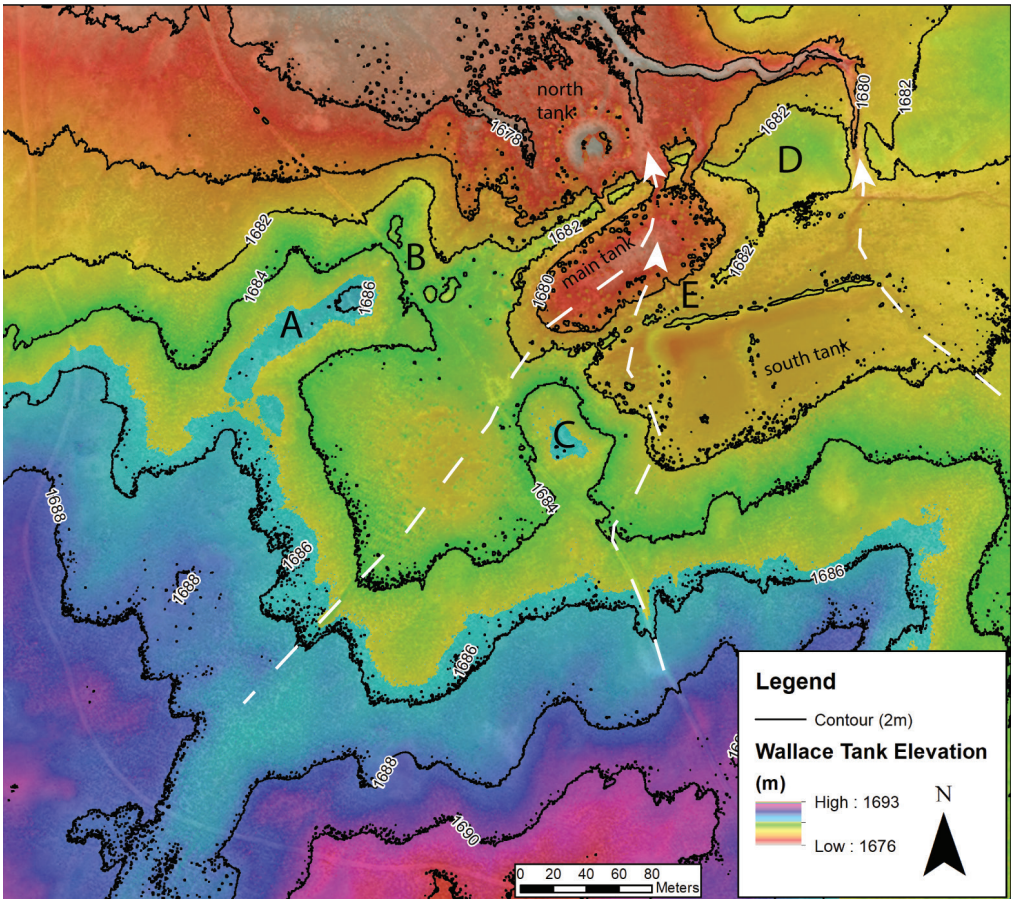


FIGURE 13. DSM showing elevation changes across the site. Higher areas are to the southwest; lower areas are to the northeast. Surface and subsurface flow (dashed white arrows) also trends in these directions. The berms and basins should be graded to the new outflow elevation.

"Traditional Hopi architecture is comprised solely of native materials such as quarried rock and flagstone, soil mortar, clay plaster, wood beams, and vegetation; all of which are products of the earth, sun, and water. These materials were respectfully taken from the earth to build our homes, and in doing so our traditional Hopi structures are literally "born" out of the earth, and this symbolic birth reflects our connection to the environment we live upon. Because of the nature of our traditional homes, we are literally surrounded by the reminder that we too, are of the earth, and someday, we will return to it. Our homes therefore serve as metaphors that we are inextricably tied to the earth and that we cannot separate ourselves from the environment we occupy."

The message from these tribal perspectives is clear – the people, their belongings, and their homes are all born out of mother earth, living together in their shared cultural landscape. Their health, and the health of their ancestors, are inextricably linked to the health of the land.

CONCLUSIONS

Although Wallace Tank Pueblo was heavily damaged over the years, there are significant parts of the site that remain untouched. The site could greatly benefit from preservation and rehabilitation work. The catastrophic emptying of the main tank has already occurred, so unless the main tank is reconstructed, which seems highly unlikely, there is no further risk of erosion from "filling and spilling". Most of the site is at a very low risk of catastrophic flooding. The parts of the site that are at low to moderate risk include: 1) portions of Roomblocks A, B and C that are crossed by the access road; 2) Roomblock D, which may eventually be impacted by headcutting near the outlets; the rate of erosion here could accelerate during the wettest seasons; and 3) the newly exposed portions of Roomblock E, which are presently experiencing ongoing rill erosion, which will continue during rainfall events.

Cultural resource managers are often limited by various practical considerations and therefore focus on risks to archaeological remains, rather than the long-term health of the cultural landscape. Although deteriorating sites may benefit from erosion control features, few undergo comprehensive re-habilitation.

Re-establishing the broader health of the Wallace Tank Pueblo cultural landscape is as important as mitigating erosion of the roomblocks. Using traditional Indigenous knowledge of a site's spiritual and emotional importance, erosion control practices of descendant communities (such as the Ancestral Lands Conservation Corps), and scientific insights of the site's geomorphic and ecosystem characteristics, Wallace Tank Pueblo's cultural landscape can be restored to a healthy, pre-cattle tank ecosystem. Berms, tanks, basins, and slopes can be recontoured, and the ancient spring that once supplied water to hundreds of individuals can be re- established. A spring-fed wetland habitat could be re-established in the location of the main tank. While we may never know the precise "original" characteristics of the site, we do know that the ancestors did not live within the confines of three large cattle tanks.

The tangible and intangible aspects of Wallace Tank Pueblo could benefit from actions to slow erosion of the built environment and re-establish the spring ecosystem. This would address the needs of cultural resource managers tasked with preserving resources, as well as the desires of members of descendant communities who wish to care for the cultural landscapes still inhabited by their ancestors.

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PREDATION OF TURKEY VULTURES BY GOLDEN EAGLES IN WALNUT CANYON NATIONAL MONUMENT, ARIZONA

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ABSTRACT – Golden Eagles (*Aquila chrysaetos*) and their diets have been studied extensively in North America and beyond. There have, however, been minimal studies of this species conducted in the state of Arizona, and none within Walnut Canyon National Monument. This ongoing study is focused on the diet of Golden Eagles that have nested in Walnut Canyon National Monument since at least 2008. Analysis of prey remains collected from their nests provides a baseline sample of their dietary habits, but also reveals a much higher proportion of Turkey Vultures (*Cathartes aura*) than is reported from any other Golden Eagle study in the country, with vultures making up more than 24% of individuals identified from the assemblage.

Keywords: Golden Eagle, prey remains, raptor, Turkey Vulture, osteology

INTRODUCTION

It is widely reported throughout much of western North America that jackrabbits, specifically *Lepus californicus*, represent a top or *the* top prey species of the Golden Eagle (Bloom and Hawks, 1982; Collopy, 1983; Eakle and Grubb, 1986; Mollhagen et al., 1972; Olendorf, 1976; Stahlecker et al., 2009). Studies conducted in the Pacific Northwest reveal a shift away from hares and toward ground squirrels (marmots and smaller ground squirrel species), as favorite prey species (Marr and Knight, 1983; Watson and Davies, 2015). Overall, North American studies describe mammals as constituting about 80% or more of the Golden Eagle diet, with bird species accounting for around 20% or less (Bloom and Hawks, 1982; Collopy, 1983; Eakle and Grubb, 1986; Marr and Knight, 1983; Mollhagen et al., 1972; Olendorf, 1976; Watson and Davies, 2015). Collins and Latta's 2009 Channel Islands study stands out as the only study to date in which birds make up the majority of Golden Eagle prey remains, at 52.2% (MNI = minimum number of individuals), or "the highest percentage for birds recorded in the diet of any golden eagle population in North America" (Collins and Latta, 2009: 264). Though an array of bird species is described from previous North American Golden Eagle prey studies, collectively, a total of just four Turkey Vultures have been reported as prey items, including one from Eakle and Grubb's 1986 study of nine nests in central Arizona and three from Carnie's six-year study of 17 Golden Eagle pairs in the coastal ranges of central California (Carnie, 1954).

The dietary habits of Golden Eagles (*Aquila chrysaetos*) in Walnut Canyon National Monument have not been previously researched, and only three similar studies have taken place within the state of Arizona (Eakle and Grubb,

1986; Stahlecker et al., 2009; Losee et al., 2019). This paper reports on the first two years of ongoing analysis of prey remains collected from Golden Eagle nest sites in the monument, and the resulting first documented occurrence of focused predation of Turkey Vultures by Golden Eagles.

METHODS

Walnut Canyon National Monument is characterized by 16 kilometers of sinuous canyon system stretching the length of the 1400-hectare monument to an average depth of 120 meters. The canyon was formed over the past six million years as erosive forces exposed the Kaibab limestone and Coconino sandstone geologic layers (Figure 1).

In 2021 and 2022, we collected all prey items (skeletal elements and feathers), found at two Golden Eagle nest sites in the monument, both of which are utilized by a single nesting pair. The two nests, which are separated by approximately 300 meters, are located on a continuous band of vertical cliff walls and cannot be accessed without the use of technical climbing gear. Areas at the base of these cliffs (located directly below the large stick nests and extending outward in a 15-meter radius) were searched for prey remains by three surveyors for a period of 4 hours. All prey remains were collected and transported to lab facilities for identification, quantification and analysis. To avoid disruption of nesting birds, prey collections were conducted in November, outside the local Golden Eagle nesting season, after young of the year had departed the area and before adults returned for the next breeding season.

All prey items identified were done so by direct, one-to-one comparison with voucher specimens from the Petrified Forest National Park Natural History Collections, the University of Montana Philip L. Wright Zoological Museum, and those curated by the primary author. Drost's (2009) *Inventory of Mammals of Walnut Canyon, Wupatki and Sunset Crater Volcano National Monuments* technical report, the 2010 *Avian Inventory of Walnut Canyon* Report, Hoffmeister's (1986) *Mammals of Arizona*, and published vertebrate osteology manuals also aided in the identification process (Cohen and Serjeantson, 1996; Elbroch, 2006; Gilbert et al., 1996; Gilbert, 1990). All bird bone not identifiable to the genus level, and all mammal bone not identifiable to the order level, were considered unidentified .

The prey analysis approach of collecting remains from in and around bird nesting sites, though widely used, is most likely biased toward prey items brought to the nests to feed young versus items consumed by adults offsite. Additionally, smaller sized prey items may be underrepresented by these collection methods due to their loss through being embedded within the stick nest, through secondary predator consumption, or due to whole bone destruction through primary predator ingestion (Bedrosian et al., 2017; Marti et al., 2007; Mollhagen et al., 1972).

RESULTS

The 2021 collections resulted in the identification of a minimum of 74 individual animals from 461 prey items, representing at least 12 species – seven bird and five mammal - (Table 1). This assemblage consisted of 61.6% mammals and 38.4% birds, with no evidence of reptile, amphibian or fish prey remains. Mammals made up

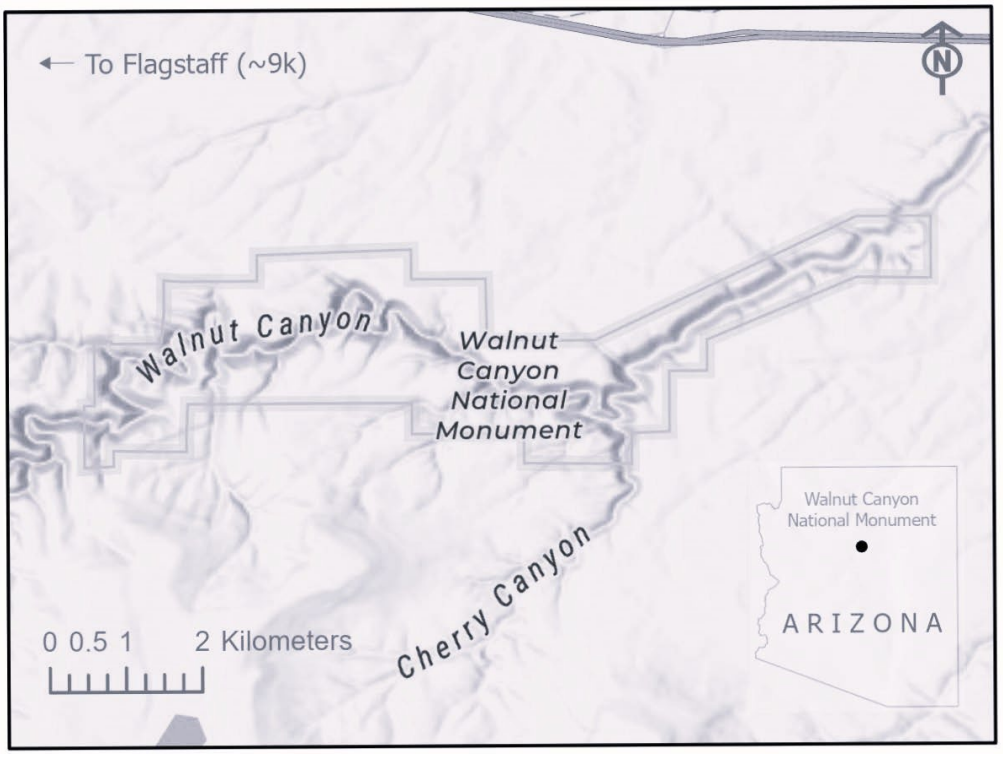


FIGURE 1. Walnut Canyon Monument, Arizona

approximately 53.0% of the total biomass, with birds accounting for 47.0%. Black-tailed jackrabbits accounted for 28.0% of the total individual animals identified, with 21 individuals represented in the assemblage, followed closely by 20 individual Turkey Vultures, representing some 27% of individual animals With 6 individuals, the Common Raven (*Corvus corax*), made up about .08% of individuals, followed by desert cottontail (*Sylvilagus audubonii*) at 5 individuals, accounting for nearly .07%. Rock squirrels (*Spermophilus variegatus*) represented a little more than .05%, with 4 individuals. Avian species represented by two or fewer individuals included Great-blue Heron (*Ardea herodias*), Barn Owl (*Tyto alba*), American Crow (*Corvus brachyrhynchos*), Domestic Rooster (*Gallus gallus domesticus*), and either Western or Clark's Grebe (*Aechmophorus* sp.). Mammals rounding out the assemblage included striped or hog-nosed skunk (Mephitidae), unidentified woodrat (*Neotoma* sp.), unidentified squirrel (Sciuridae) and elements from two unidentified immature ungulates. It is important to note that the data reported from the 2021 collecting event represented the first-time collection of prey items from these locations. Therefore, we believe these collected items included prey remains from multiple nesting episodes over multiple years. Significant weathering observed on a portion of the prey items attests to their long-term exposure to a variety of environmental agents.

The 2022 collections represented the first single-year accumulation data collected from the nest locations. This assemblage consisted of a minimum of

TABLE 1. 2021 Golden Eagle prey totals (multi-year accumulation). *NISP = number of identified specimens; *MNI = minimum number of individuals

Taxon / Common Name	*NISP	*MNI	Average Weight (kg)	Biomass (kg)	Proportion of Individual Animals (%)	Proportion of Biomass (%)
BIRDS						
Cathartes aura Turkey Vulture	75	20	1.6	32	27	28.1
Corvus corax Common Raven	31	6	1.2	7.2	8	6.3
Ardea herodias Great Blue Heron	11	2	2.3	4.6	2.7	4.0
Tyto alba Barn Owl	2	1	0.5	0.5	1.4	0.4
Corvus brachyrhynchos American Crow	1	1	0.5	0.5	1.4	0.4
Gallus gallus domesticus Domestic Rooster	1	1	2.6	2.6	1.4	2.3
Aechmophorus sp. Grebe (western / Clark's)	1	1	1.4	1.4	1.4	1.2
unidentified medium/large bird	52	-	-	-	-	-
MAMMALS						
Lepus californicus black-tailed jackrabbit	170	21	2.1	44.1	28.4	38.7
Sylvilagus audubonii desert cottontail	38	5	1	5	6.8	4.4
Spermophilus variegatus rock squirrel	12	4	0.7	2.8	5.4	2.5
Mephitidae skunk (striped / hog-nosed)	1	1	3.2	3.2	1.4	2.8
Neotoma sp. unidentified woodrat	1	1	0.5	0.5	1.4	0.4
Sciuridae unidentified squirrel	1	1	0.7	0.7	1.4	0.6
Leporidae hare / rabbit	54	5	1.6	8	6.8	7.0
Rodentia unidentified small rodent	7	2	0.4	0.8	2.7	.07
Ungulate unidentified hoofed mammal	3	2	-	-	2.7	n/a
Totals:	461	74	-	-	100	100

TABLE 2. 2022 Golden Eagle prey totals (single-year accumulation). *NISP = number of identified specimens; *MNI = minimum number of individuals

Taxon / Common Name	*NISP	*MNI	Average Weight (kg)	Biomass (kg)	Proportion of Individual Animals (%)	Proportion of Biomass (%)
BIRDS						
Cathartes aura Turkey Vulture	81	7	1.6	11.2	19.4	20.5
Corvus corax Common Raven	14	4	1.2	4.8	11	8.7
Ardea herodias Great Blue Heron	3	1	2.3	2.3	2.7	4.2
Strix occidentalis lucida Mexican Spotted Owl	1	1	0.7	0.7	2.7	1.2
Buteo jamaicensis Red-tailed Hawk	1	1	1.1	1.1	2.7	2
unidentified medium/ large bird	12	2	-	-	5.6	-
MAMMALS						
Lepus californicus black-tailed jackrabbit	92	9	2.1	18.9	25	34.6
Sylvilagus audubonii desert cottontail	5	3	1	3	8.3	5.4
Spermophilus variegatus rock squirrel	4	2	0.7	1.4	5.6	2.5
Mephitidae skunk (striped / hog-nosed)	3	3	3.2	9.6	8.3	17.6
Neotoma sp. unidentified woodrat	4	2	0.5	1.0	5.6	1.8
unidentified small mammal	10	1	0.7	0.7	2.7	1.2
Totals:	230	36	-	-	100	100

36 individual animals identified from 230 prey items, representing at least 10 species – five bird and five mammal - (Table 2). Though overall prey numbers were lower, as would be expected from the single year of prey accumulation versus the multi-year accumulations from the previous year, the most common species and their relative percentages remained largely the same. Turkey Vultures continued to be the most represented bird species, with a minimum of 7 individuals identified from 81 bones, followed by Common

Raven with 4 individuals and Great Blue Heron at 1 individual. The 2022 collections also included the remains of Mexican Spotted Owl (*Strix occidentalis lucida*) and Red-tailed Hawk (*Buteo jamaicensis*), neither of which were present in the previous year's assemblage, while American Crow, Barn Owl, Domestic Rooster and Grebe, identified in 2021, were absent from the 2022 collections. Identified mammal species remained the same from year one to year two, with black-tailed jackrabbit being the most common, with a minimum of 9 individuals identified from 92 bones, followed by desert cottontail and rock squirrel.

DISCUSSION

The Walnut Canyon nesting sites have been continuously occupied and monitored since 2008, and 13 successful nesting events have been documented in that time. This information verifies that all collected prey remains reported here originated from Golden Eagle predation (and potential scavenging), and not from the efforts of another large raptor such as the Great Horned Owl (*Bubo virginianus*), a species that may nest in similar environs as that of the Golden Eagle, and that is known to use the unoccupied nest of other large-bodied birds of prey.

Golden Eagle feeding habits, specifically their strategies for disarticulating prey, can be partially illuminated by noting the particular skeletal elements that remain at the nest site following the nesting season. In the case of bird species consumed by the Walnut Canyon eagles, 150 of 189 total diagnostic bones, or just under 80% of those identified to genus level or above, belonged to elements that make up the shoulder/wing assemblages (Table 3). The four most represented avian skeletal elements were the humerus, radius, ulna and carpometacarpus, pointing to the removal and discarding of wing elements prior to focusing on the main body, a method of consumption noted by previous investigators working with raptor prey remains (Guilday et al., 1980). This may suggest the eagles are targeting the nutrient-rich organs and muscles of the main bodies, resulting in the consumption of much of the axial and lower limb elements. Ravens appear to be the exception to this trend, with leg elements, specifically femora and tibiotarsi, being their most represented elements in the assemblage, possibly suggesting a different consumption strategy for this species.

Compared with similar studies conducted in western North America (Bloom and Hawks, 1982; Collopy, 1983; Eakle and Grubb, 1986; Mollhagen et al., 1972; Olendorf, 1976; Stahlecker et al., 2009), these results reveal a much larger percentage of avian prey in the Walnut Canyon National Monument Golden Eagle's diet, with birds accounting for nearly 40.0% of their dietary composition, or about twice that of other studies. The single standout exception being the Collins and Latta (2009) study in which birds make up 52% of the prey assemblage. The Walnut Canyon National Monument Eagle's apparent focus on Turkey Vultures is particularly unique, with vultures accounting for more than 56% of *all* bird remains identified from the assemblage, numbers that stand out from all other dietary accounts reviewed from North America and beyond, including those containing relatively high percentages of bird remains (Collins and Latta, 2009).

Large Turkey Vulture kettles regularly form above Walnut Canyon in the Spring

TABLE 3. Diagnostic bird skeletal elements from the 2021 and 2022 Golden Eagle prey assemblages

Skeletal Element	Turkey Vulture	Common Raven	Great Blue Heron	Barn Owl	Crow	Domestic Rooster	Mexican Spotted Owl	Red-tailed Hawk	Western or Clark's Grebe	
Cranium	1	1	1	-	-	-	-	-	-	3
Dentary	3	-	2	-	-	-	-	-	-	5
Radius	26	-	2	-	-	-	-	-	-	28
Ulna	28	6	-	-	-	-	-	-	-	34
Humerus	28	7	3	-	-	-	1	1	-	40
C-metacarpus	19	2	-	-	-	-	-	-	-	21
Coracoid	18	6	4	-	-	-	-	-	-	18
Scapula	4	1	-	-	-	-	-	-	-	5
Furculum	4	-	-	-	-	-	-	-	-	4
Sternum	2	-	-	1	1	-	-	-	-	4
Femur	3	11	-	-	-	-	-	-	-	14
Tibiotarsus	-	9	-	1	-	-	-	--	1	11
T-metatarsus	-	1	-	-	-	1	-	-	-	2
Totals:	126	44	12	2	1	1	1	1	1	189

and Summer months, as the birds take advantage of the thermal air currents rising from the exposed limestone and sandstone cliff walls. Though this behavior is common in and around canyons and mountainous terrain across much of the Turkey Vulture and Golden Eagle's overlapping ranges, for reasons that remain unclear, Walnut Canyon's eagles appear to have developed more of a focus on Turkey Vultures as prey than has been reported outside this study area (Figure 2). A former biologist at the monument observed a snapshot of this predatory focus firsthand as he reported seeing a Golden Eagle aggressively pursuing a Turkey Vulture, with the vulture apparently only avoiding capture by swiftly dropping below the canyon rim and maneuvering through semi-dense tree cover (B. Hetzler, personal communication, June 6, 2021). National Park Service resources staff continue annual collection of prey items at these nest locations, with results from the study helping to directly inform park-specific management strategies that support the prey of this federally protected eagle.



FIGURE 2. Turkey Vulture cranium from the 2022 prey assemblage

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A LATERAL OSTEODERM FROM *KRYPHIOPARMA CAERULA* (PSEUDOSUCHIA: AETOSAURIA) FROM THE UPPER TRIASSIC (NORIAN) CHINLE FORMATION OF ARIZONA

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ABSTRACT — Recent collecting of fossil vertebrates in the Chinle Formation at Petrified Forest National Park (PEFO) and reinvestigation of historic collections resulted in the recognition of a new aetosaurian taxon, *Kryphioparma caerula.* Although distinctive, *K. caerula* was initially described from several fragmentary paramedian osteoderms from PEFO and the nearby *Placerias* Quarry, however the anatomy of the lateral osteoderms remained unknown. Here, we refer an isolated lateral osteoderm from the *Placerias* Quarry to *K. caerula* based on an ornamentation composed of large elliptical-to-rounded pits on the dorsal surface that are randomly arranged, a prominent anterior bar, a strongly obtuse angle between two partially preserved flanges, an elongate lateral eminence (spine) with a strongly embayed posterior margin, and sharp anterior ridge. This combination of anatomical features of the isolated lateral osteoderm is clearly aetosaurian and differs in significant ways from the other known aetosaurian taxa from the site. A parsimony analysis recovers *K. caerula* nested within the inclusive clade Typothoracinae. This lateral osteoderm demonstrates that *K. caerula* was a spinose aetosaur, a bauplan observed in both typothoracine and desmatosuchin aetosaurians. Thus, further highlighting observed convergence between these groups and indicating a need for a reevaluation of lateral osteoderm characters used for phylogenetic analyses.

Keywords: Osteoderms, Triassic, Aetosauria, Chinle Formation, *Kryphioparma*, *Placerias* Quarry.

INTRODUCTION

The Late Triassic Aetosauria are an uncommon vertebrate group for study not only because of their heavy carapace, but also because, unlike many Triassic armored animal groups (e.g., phytosaurs, paracrocodylomorphs), the surface ornamentation and overall morphology are often diagnostic to species (Long and Ballew, 1985; Desojo et al., 2013). The carapace consists primarily of four columns of osteoderms that are subdivided into four columns covering the back from the posterior edge of the skull to the tip of the tail. The two inner columns are composed of quadrangular paramedian osteoderms that straddle the midline, and the two outer columns are composed of flexed lateral osteoderms following the terminology of Long and Ballew (1985). Whereas the surface ornamentation of aetosaurian osteoderms is traditionally used to diagnose taxa (Long and Ballew, 1985; Heckert and Lucas, 2000), the nature of the articulation between the paramedian

and lateral osteoderms is also recognized to be of high taxonomic and phylogenetic importance (Parker, 2007; 2016).

The *Placerias* Quarry (UCMP A269; MNA loc. 207) located southwest of St. Johns, Arizona in northeastern Arizona, U.S.A. is one of the most speciose fossil quarries with regard to aetosaurs (Long and Murry, 1995; Parker, 2005a; Parker, 2018; Reyes et al., 2023). Aetosaurian taxa currently recognized from the *Placerias* Quarry are *Calyptosuchus wellesi*, *Desmatosuchus spurensis*, *Desmatosuchus smalli*, *Kryphioparma caerula*, and an unnamed paratypothoracin (Camp and Welles, 1956; Long and Ballew, 1985; Long and Murry, 1995; Heckert and Lucas, 2000; Parker, 2005a; Parker, 2018; von Backzo et al., 2021; Reyes et al., 2023). The aetosaurian materials from the quarry also include numerous non-osteoderm elements that have been used for braincase and limb histology studies (e.g., de Ricqlès et al., 2003; von Backzo et al., 2021). Unfortunately, associations with osteoderms were not noted when these elements were originally collected so the assignment of many of these bones to specific taxa is problematic (see discussion in Parker, 2018). Three institutions house the *Placerias* Quarry collections: 1) the University of California Museum of Paleontology; 2) the Museum of Northern Arizona; and 3) the North Carolina Museum of Natural Sciences.

Recent excavations at the PEFO locality PFV 456 (Thunderstorm Ridge; Reyes et al., 2023:fig. 1) recovered osteoderms from four different aetosaurians (Reyes et al., 2023). Two osteoderm fragments (PEFO 51662, PEFO 46468) shared characteristics with ambiguous fragmentary osteoderms (UCMP 165173, UCMP 126847) from the *Placerias* Quarry; these elements formed the basis for a new aetosaurian taxon, *Kryphioparma caerula* Reyes et al. (2023). Although *K. caerula* is only known from fragmentary paramedian osteoderms leaving the rest of the skeleton unknown, Reyes et al. (2023) suggested that *K. caerula* is more closely related to typothoracines (sensu Parker, 2016) based on the ornamentation and overall dimensions. While examining material from the *Placerias* Quarry at the MNA, we recognized the distinctness of an isolated lateral osteoderm (MNA V3742) that exhibits a shared ornamentation with *K. caerula*. Long and Murry (1995) originally assigned this specimen to Desmatosuchus spurensis without discussion but in this contribution, we describe and figure this specimen, formally refer it to *K. caerula*, and provide further support for the taxon as a possible typothoracine.

MATERIALS AND METHODS

Only a single lateral osteoderm (MNA V3742) is described in this study. This specimen was collected in 1978 by staff from the Museum of Arizona (Jacobs and Murry, 1980). Preparation was also completed at that facility. Preparation appears to mostly have been the removal of siliciclastic matrix using hand tools, and the application of a hard substance, presumably to stabilize the medial surface, which has not been completely freed of matrix.

The phylogenetic analysis includes a total of 28 ingroup taxa and 104 characters following the published analyses by Parker (2016), Paes-Neto et al. (2021), Reyes et al. (2020, 2024) and Haldar et al. (2023). In this present study we have used the third iteration of Reyes et al., 2024 where they scored all the osteoderms of the newly described aetosaur

Garzapelta muelleri (Reyes et al., 2024). The dataset was constructed in PAUP* 4.0 (Swofford, 2003) and exported as a NEXUS (Maddison et al., 1997) file. The matrix was analyzed in TNT version 1.5 (Goloboff and Catalano, 2016). *Postosuchus kirkpatricki* was used as an operational outgroup and *Revueltosaurus callenderi* was the second outgroup. *Kryphioparma caerula* was scored using the osteoderm material presented by Reyes et al. (2023) and the new osteoderm described here. The analysis was performed using the Traditional search with 1000 replications and tree bisection reconnection with 10 trees per replication. 14 characters were considered ordered (3, 4, 14, 20, 22, 23, 24, 28, 64, 70, 73, 76, 79, 83) following the previous analyses by Parker (2016), Paes-Neto et al. (2021) and Reyes et al. (2020, 2024). Systematic resampling (Goloboff et al., 2003; Goloboff and Catalano, 2016) was executed with 1000 replicates with a removal probability of 5. Our analysis pruned *Aetobarbakinoides brasiliensis* similar to previous studies which recognized it as a wild card taxon as discussed in Parker (2016). We also omitted *Polesinesuchus aurelioi*, following Haldar et al., 2023, as it is considered a junior synonym of *Aetosauroides scagliai* by Paes-Neto et al. (2021).

Institutional Abbreviations — **MNA**, Museum of Northern Arizona, Flagstaff, AZ, U.S.A.; **NMMNH**, New Mexico Museum of Natural History and Science, Albuquerque, NM, U.S.A.; **PEFO**, Petrified Forest National Park, Arizona, U.S.A.; **PFV**, Petrified Forest National Park Vertebrate Locality; **TMM**, Texas Memorial Museum collections, Vertebrate Paleontology Laboratory, University of Texas at Austin, Austin, TX, U.S.A.; **TTU-P**, The Museum at Texas Tech University, Lubbock, TX, U.S.A.; **UCMP**, University of California Museum of Paleontology, Berkeley, CA, U.S.A.; **UMMP**, University of Michigan Museum of Paleontology, Ann Arbor, MI, U.S.A.

SYSTEMATIC PALEONTOLOGY

ARCHOSAURIA Cope, 1869, *sensu* Gauthier and Padian, 1985

PSEUDOSUCHIA Zittel, 1887-90, *sensu* Gauthier and Padian, 1985

AETOSAURIA Marsh, 1884, sensu Parker, 2007

AETOSAURINAE Marsh, 1884, *sensu* Heckert and Lucas, 2000

TYPOTHORACINAE von Huene, 1915, *sensu* Parker 2016

KRYPHIOPARMA CAERULA Reyes et al., 2023

Figs. 1A–D, 3A–B

1995 *Desmatosuchus haplocerus*: Long and Murry, p. 233.

Holotype. — UCMP 165175, incomplete right paramedian osteoderm.

Paratype. — UCMP 126847, incomplete osteoderm.

Type Horizon and Age. — UCMP A269/ MNA loc. 207, *Placerias* Quarry, Apache County, Arizona. Late Triassic, early-middle Norian, upper Blue Mesa Member/lower Sonsela Member, ~223-218 Ma based on U-Pb detrital zircon maximum depositional age (Ramezani et al., 2014; Rasmussen et al., 2020; Reyes et al., 2023: fig. 1). Adamanian estimated holochronozone (Martz and Parker, 2017).

Locality ownership. — The *Placerias* Quarry is presently on Arizona State Trust land and requires permits from the Arizona State Museum and the Arizona State Lands Department to access and collect.

Referred Specimens. — PEFO 51662 and PEFO 46468, partial osteoderms.

New Referred Specimen. — MNA V3742, right lateral osteoderm. Collected by the MNA during the 1978 excavations of the *Placerias* Quarry led by Louis Jacobs and Will Downs.

Referred Specimen Horizon and Age. — Same as the type specimen horizon.

Rationale for referral. — MNA V3742 bears a unique combination of characters that differentiate it from the lateral osteoderms of other aetosaurians. The surface ornamentation is composed of randomly oriented oblong pits differentiates it from all other aetosaurians except for *Desmatosuchus*, *Sierritasuchus*, and *Longosuchus* (Small, 1985; Parker, 2008; Parker et al., 2008), non-paratypothoracin typothoracines (Parker, 2016), as well as the paramedian osteoderm of *Kryphioparma caerula* (Reyes et al., 2023). The presence of a pronounced anterior bar and the thinness of the lateral flange, the straight and elongated spine, the embayment in the posterior edge on the posterior side of the spine, and the thinness of the lateral flange distinguish it from the lateral osteoderms of *Desmatosuchus* (e.g., TTU P-9024) which exhibit thick lateral plates with a posteriorly recurved lateral spine and an anteriorly depressed lamina (*sensu* Long and Ballew, 1985) along the anterior margin instead of a raised bar (Parker, 2005b, 2008). The combination of characters precludes MNA V3742 from being referred to the other aetosaurs documented from the *Placerias* Quarry (i.e., *Desmatosuchus*, *Calyptosuchus wellesi* and an unnamed paratypothoracin; Long and Murry, 1995; Parker, 2005a, 2018; von Baczko et al., 2021; Reyes et al., 2023). The lateral osteoderm of *Kryphioparma* strongly differs from the laterals of *Calyptosuchus wellesi* (PEFO 46222) in having a laterally extended, straight, elongated spine, with a predominantly random dorsal surface ornamentation, unlike the strong radial surface ornament of pits ridges and grooves in those of *C. wellesi* (Parker, 2018).

Revised Diagnosis. — In addition to the diagnosis for the paramedian osteoderms provided by Reyes et al. (2023), *K. caerula* can be distinguished from other aetosaurs by a unique combination of characters of the lateral osteoderms: randomly arranged ornamentation of oblong pits (unlike *Typothorax*, *Redondasuchus*, *Apachesuchus*, and aetosaurs with radial patterns composed of grooves and ridges); the presence of an anterior bar (shared with all aetosaur taxa except *Desmatosuchus*); a rectangular lateral flange (shared with desmatosuchins and *Garzapelta*); an elongate lateral eminence (spine) that is straight, projects laterally, and is emarginated at its ventral base (unlike the elongated, recurved spine in *Paratypothorax, Longosuchus, Lucasuchus, Desmatosuchus* and *Garzapelta*); a spine that is oval in cross-section and bears a strong sharp ridge along the anterior edge.

DESCRIPTION

MNA V3742 is an incomplete right lateral osteoderm missing most of the dorsal flange (*sensu* Parker, 2007) and the tip of the lateral eminence (spine) (Fig. 1). The entire element as preserved

measures 7 cm wide (mediolaterally) and 5.5 cm long (anteroposteriorly). The lateral flange is 4 cm wide and the incomplete lateral eminence measures 3.7 cm long. Another fragment in the collections box may represent the missing dorsal flange, but there is no direct fit and the coloration is slightly different between the elements. Because of this we do not include it in the description.

The osteoderm bears a distinct raised anterior bar (*sensu* Long and Ballew, 1985) that is separated from the main body of the osteoderm by a shallow trough (Figs. 1A-B). The lateral flange is thin, rectangular in lateral view, and is transversely longer than wide in dorsal view (Fig. 1A). It bears a dorsal surface ornamentation of almost equidimensional, elongate pits arranged randomly with no hint of a radial pattern (Fig. 1B). The posterolateral edge (corner) of the lateral flange is subrounded and bears a prominent smooth raised rim (Fig. 1B). The dorsal flange is broken and incomplete, but what is present shows that it also had a surface ornamentation of deeply incised oblong pits. It also appears that the dorsal flange was rectangular. The two flanges meet at an obtuse angle beneath the lateral eminence in anteroposterior view (Fig. 1C).

The most characteristic feature of the osteoderm is the lateral eminence that forms a straight spine that extends laterally (Fig. 1C). The spine is oval in cross-section (Fig. 1A) and bears a strong anterior ridge that extends along the entire preserved length. The surface ornamentation of the spine is rugose with small pits and short grooves. The posterior embayment is prominent, has confluent edges with the dorsal and lateral flanges, and excavates the base of the spine (Fig. 1C). The spine tip is missing but if complete would probably have extended the length of the spine by at least another 3 centimeters (Fig. 1C). The posterior edge of the spine contacts the posterior margin of the osteoderm. Most notably, as preserved the spine projects laterally and does not appear to curve posteriorly or anteriorly.

COMPARISONS

Overall, the lateral osteoderm of *K. caerula* (Figs. 2A, B) most closely resembles those of desmatosuchines, but differs from *Desmatosuchus* (TTU P-9024, Fig. 2C) in having a laterally projecting straight spine with a pronounced keel, a posterior emargination of the spine, and a raised anterior bar. It differs from *Sierritasuchus macalpini* (UMMP V60817) and *Longosuchus meadei* (TMM 31185-84) in having a straight spine that is not posteriorly curved, and from *S. macalpini* in that the spine is not strongly dorsoventrally compressed. It differs from the laterals of *Calyptosuchus wellesi* (Fig. 2G; Long and Murry, 1995) in having an elongated spine and in lacking a radial ornamentation.

MNA V3742 differs from paratypothoracins such as *Paratypothorax* (PEFO 3004; Lucas et al., 2006), *Rioarribasuchus* (NMMNH P-35993; Parker, 2007), and *Tecovasuchus* (TTU P-545; Martz and Small, 2006) in having a laterally projecting straight spine, by the lack of radial ornamentation, and by the possible presence of a rectangular dorsal flange. In *Typothorax*, *Paratypothorax* and *Tecovasuchus* (Figs. 2D-F, H; Long and Murry, 1995; Martz and Small, 2006), the ventrolateral flange is broad and incised with sub-parallel grooves radiating from the tip of the dorsoventrally flattened spine unlike the pattern in MNA V3742. Consequently,

the lateral osteoderm of *Kryphioparma* is also distinct from the paratypothoracin *Garzapelta muelleri* (Reyes et al., 2024) which has the weakly formed anterior bar (sensu Long and Ballew, 1985) found in all paratypothoracins rather than the depressed lamina found in *Desmatosuchus*. Moreover, *Garzapelta* lacks a posterior embayment at the posterior margin of the dorsal spine. Furthermore, the dorsal spine of *Garzapelta* is posteriorly recurved unlike *Kryphioparma* and, the surface ornamentation surrounding the dorsal eminence is truly radial, composed of ridges and grooves in sharp contrast to the randomly arranged, deeply incised pits in *Kryphioparma*.

MNA V3742 is also distinct from the laterals of the Indian paratypothoracin *Venkatasuchus* (Haldar et al., 2023:fig. 7A–X) which have a weakly developed anterior bar and exhibit a strongly acute angle between the two flanges; along with a dorsoventrally flattened lateral spike similar to *Paratypothorax* and *Tecovasuchus*, and a wide ventral flange which is very faintly ornamented with

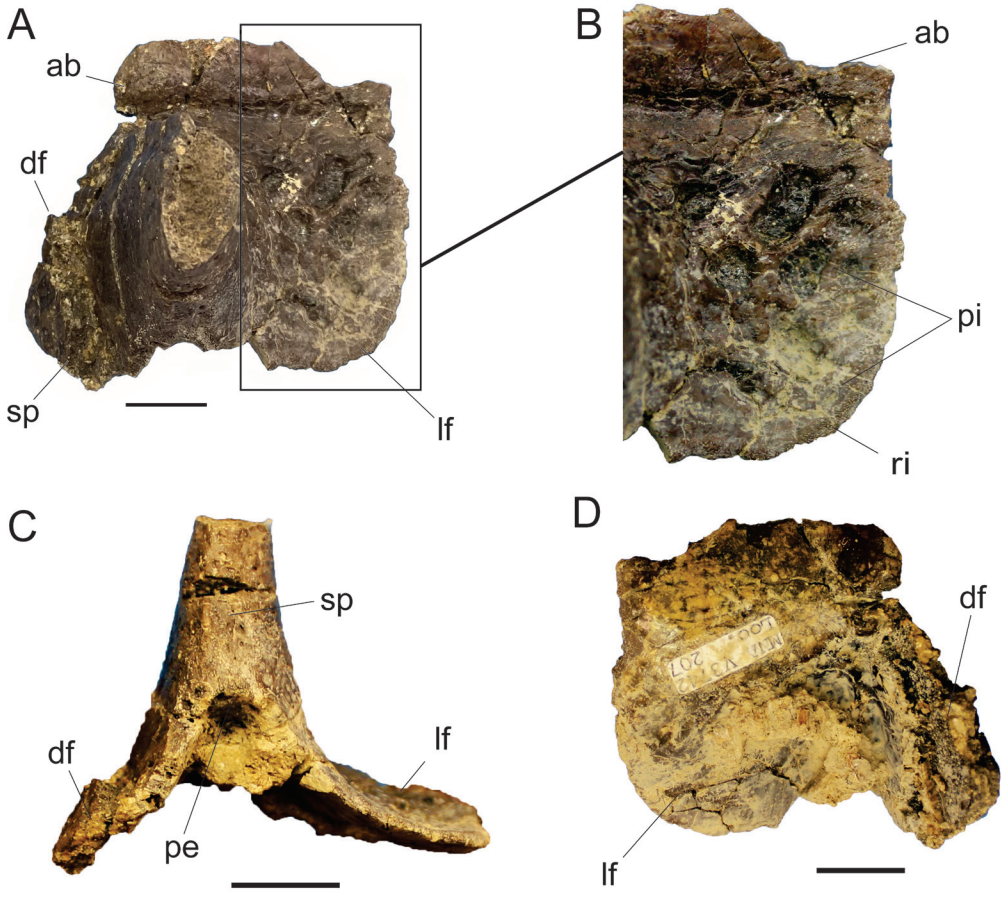


FIGURE 1. *Kryphioparma caerula* referred lateral osteoderm (MNA V3742) in A) lateral, B) lateral (close-up), C) ventral, and D) medial views. Abbreviations: **ab**, anterior bar; **df**, dorsal flange; **lf**, lateral flange; **pe**, posterior embayment; **pi**, pitting; **sp**, spine. Scale bars = 2 cm.

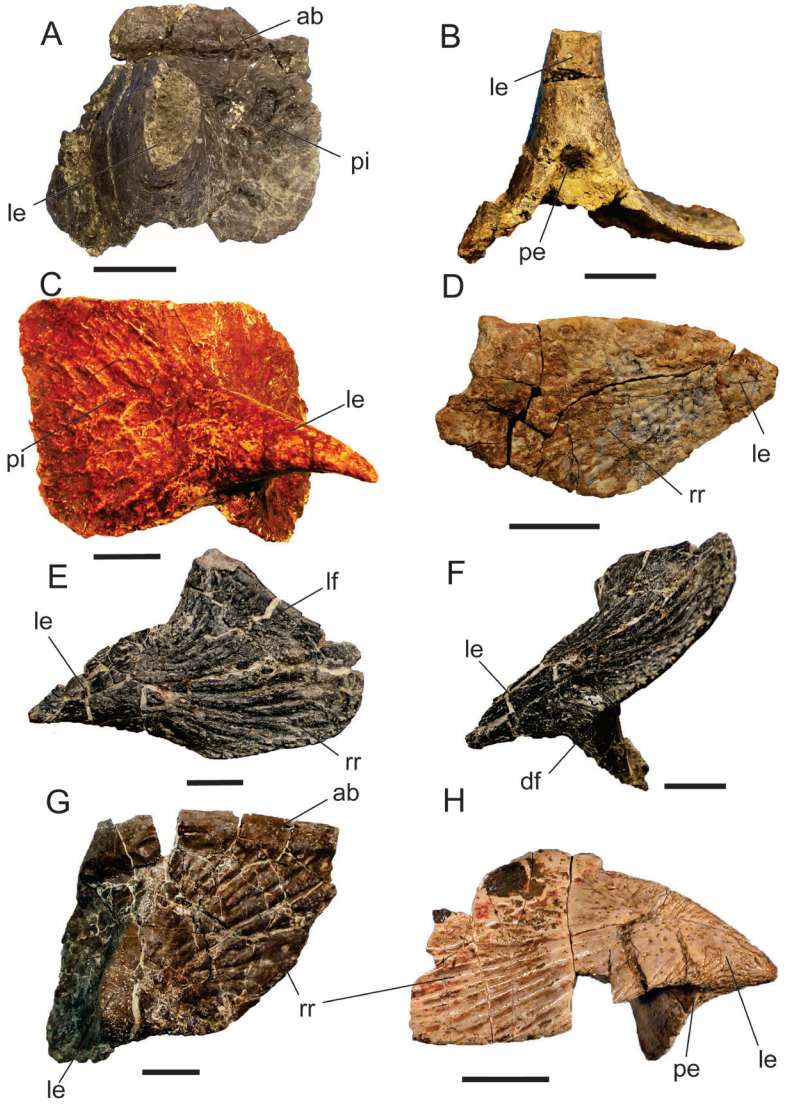


FIGURE 2. Comparative lateral osteoderms across Aetosauria. A) *Kryphioparma caerula* (MNA V3742), referred right lateral osteoderm in lateral view; B) *Kryphioparma caerula* (MNA V3742), referred lateral osteoderm in ventral view; C) *Desmatosuchus smalli* (TTU P-9024), right lateral osteoderm in dorsolateral view; D) *Typothorax coccinarum* (PEFO 33980), left lateral osteoderm in ventral view; E) *Paratypothorax* sp. (PEFO 3004), right lateral osteoderm in dorsal view; F) *Paratypothorax* sp. (PEFO 3004), right lateral osteoderm in anterior view; G) *Calyptosuchus wellesi* (PEFO 46222), right lateral osteoderm in dorsolateral view; H) *Tecovasuchus chatterjeei* (TTU P-545) left lateral view in ventral view. Abbreviations: **ab**, anterior bar; **df**, dorsal flange; **le**, lateral eminence; lf, lateral flange; **pe**, posterior embayment; **pi**, pitting; **rr**, raised ridges. Scale bars = 2 cm.

short radial ridges (Haldar et al., 2023). Additionally, the lateral osteoderms the Polish paratypothoracin, *Kocurypelta* (Czepiński et al., 2021:fig. 7D), lack a well-defined anterior bar, and the lateral flange is circular and sculptured with closely packed radial grooves which is inconsistent with the overall morphology of MNA V3742 (Czepiński et al., 2021). The straight spine might be an autapomorphy for *K. caerula*, but a more complete element is needed to verify that it was completely straight for its entire length.

RESULTS

Phylogenetic Analysis

Referral of the lateral osteoderm MNA V3742 to *Kryphioparma caerula* prompted us to perform an updated phylogenetic analysis in order to further hypothesize its phylogenetic position within Aetosauria. The results yielded 50 most parsimonious trees (MPTs) with a tree length of 292 steps. The consistency index (CI) and retention index (RI) are 0.514 and 0.674, respectively. The final analysis recovered five clades within Aetosauria (Stagonolepididae, Aetosaurinae, Stagonolepidoidea, Typothoracinae, and Desmatosuchini) concordant with previous analyses by Parker (2016), Schoch and Desojo (2016), Hoffmann et al. (2018), Reyes et al. (2020, 2024), Paes-Neto et al. (2021), and Haldar et al. (2023).

In the strict consensus tree (Fig. 3A), a significant polytomy was recovered at the base of Aetosauria although the Desmatosuchini are resolved and stable, which follows previous topologies in Parker, 2016, Schoch and Desojo, 2016, Hoffmann et al., 2018, Reyes et al., 2020, Paes-Neto et al., 2021, and Haldar et al., 2023. The significant polytomy recovered in the strict consensus tree provides little information on the relationships of *K. caerula* except that it is not a desmatosuchin (Figure 2A). The topology of the strict consensus tree is nearly identical to that of Reyes et al. (2024: Iteration 3) when including all osteoderm characters of *Garzapelta* (Reyes et al., 2024:fig. 11a). However, the topology of the strict consensus tree of our present analysis is discordant with the recent results of Haldar et al. (2023), and Iteration 1 of Reyes et al. (2024) where only the characters of the paramedian osteoderms of *Garzapelta* were scored. Notably in Haldar et al. (2023) and Reyes et al. (2024) Iteration 1 (2024) the clades Aetosaurinae, Desmatosuchini and Typothoracinae were well resolved in the strict consensus.

Thus, our analysis and Iteration 3 of Reyes et al. (2024) show that incorporation of all the characters of *Garzapelta* along with those of *Kryphioparma* reduces tree resolution and overall support in the strict consensus tree. Significantly, despite possessing paramedian osteoderm characters shared with those of typothoracine aetosaurs, both have lateral osteoderms with elongate spines and rectangular dorsal flanges, characters that previously diagnosed Desmatosuchini (Parker, 2016). Clearly one of these suites of characters is convergent and future analyses will require modification of the osteoderm character construction in the matrix to capture all known morphological diversity within Aetosauria (Reyes et al., 2024). Furthermore, because *Kryphioparma* is only known from fragmentary osteoderms it is also possibly acting as a 'wild-card taxon' (Nixon and Wheeler, 1992; Anderson, 2001; Wilkinson, 2003; Marsh et al., 2019) and may need to be pruned from future analyses until more material is assigned.

The resampled tree (Goloboff et al. 2003; Fig. 3B) is better resolved than the strict consensus tree. All the major clades such as Aetosaurinae, Stagonolepidoidea, Typothoracinae, Paratypothoracini, Desmatosuchinae and Desmatosuchini are recovered. The pruning of *Aetobarbakinoides* and *Polesinesuchus*, and addition of *Kryphioparma* did not significantly affect the tree topology recovered in previous analyses by Parker (2016), Reyes et al. (2020; 2024), Paes-Neto et al. (2021), and Haldar et al. (2023). Most importantly, however, is that *Kryphioparma caerula* is recovered near the base of Typothoracinae as sister taxon to a clade containing *Redondasuchus rineharti* + *Typothorax coccinarum*. These taxa all share a random orientation of pits on the osteoderm surface differentiating them from the paratypothoracins and the non-desmatosuchin desmatosuchines.

DISCUSSION

Kryphioparma caerula lacks discrete autapomorphic characters in the isolated osteoderms, however it exhibits a unique combination of traits that are sufficient to diagnose and differentiate it from other aetosaur taxa (Reyes et al., 2023). This condition is also true for many aetosaurs including *Calyptosuchus wellesi,* which lacks any autapomorphic characters, but possesses multiple traits which can be used to differentiate it from other aetosaurs (Parker, 2016). Previously many of the characters in the data matrices for aetosaur phylogeny were inclined towards the osteoderm characters (e.g., Heckert and Lucas, 1999; Parker, 2007; Desojo et al., 2013) rather than cranial and other post-cranial characters because most of the aetosaur taxa were described essentially from their osteoderms (Long and Ballew, 1985). However, more recent analyses have attempted to address this discrepancy by adding more non-osteoderm characters (e.g., Parker, 2016). These additions provided more resolution and stability in subsequent analyses (e.g., Hoffman et al., 2018; Paes-Neto et al., 2021; Reyes et al., 2020), although character conflict between anatomical modules (e.g., skull vs. osteoderm characters) remains an unresolved issue (Parker, 2016). However, the recent discovery of typothoracines with lateral osteoderm characters that are convergent with those of desmatosuchins (i.e., *Garzapelta* and *Kryphioparma*) reveals the limitations of existing character constructions, indicating that they are not accounting for all of the anatomical diversity found in aetosaur osteoderms, especially the laterals. The recent study by Reyes et al., 2024, provided several modifications in the character scorings of different taxa and added 6 more osteoderm characters to accommodate this disparity, however this did not result in better resolution or stability of the tree. Our data set for *Kryphioparma caerula* is restricted based on incomplete material, and its inclusion results in a reduction of tree support, but for the purposes of this study the present analysis clarifies the position of *K. caerula* within Typothoracinae supporting the previous hypothesis of Reyes et al. (2023) regarding its relationships within Aetosauria. We withhold discussion of the rest of the tree results as they are not intended to be a full analysis of the Aetosauria pending the required matrix construction modifications mentioned above.

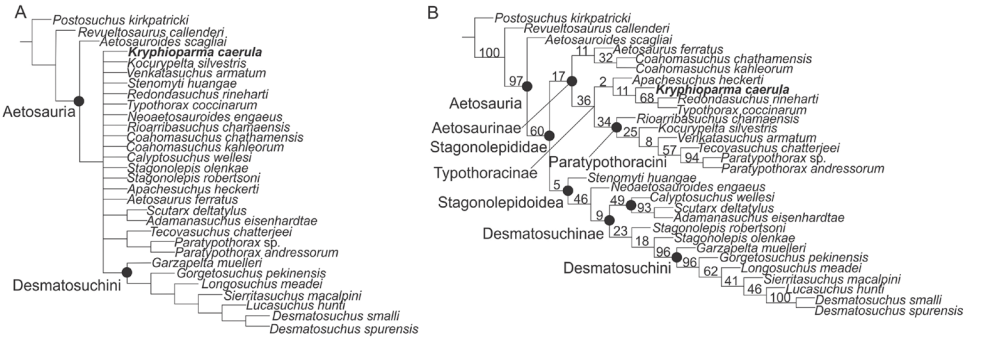


FIGURE 3. Results of the phylogenetic analysis of Aetosauria including *Kryphioparma caerula.* A) Strict consensus tree; B) systematic resampling tree. Major clades are labelled. Numbers represent bootstrap support values.

CONCLUSION

Because the dorsal ornamentation of MNA V3742 closely resembles that of *Kryphioparma caerula* and is different from those of other known taxa from the *Placerias* Quarry, we refer MNA V3742 to *K. caerula*. Although we cannot ascertain the exact position of this osteoderm in the carapace, we hypothesize it may have occupied a position in posterior region of the trunk or the sacrum based on the pronounced details of the ornamentation and the length of the spine.

The position of *Kryphioparma caerula* in our parsimony analysis endorses the previous hypothesis that *K. caerula* is more similar to the typothoracines (Reyes et al., 2023). Our analysis recovers *K. caerula* in a basal position within Typothoracinae as sister taxon to (*Typothorax coccinarum* + *Redondasuchus rineharti*). However, the support for this position is low, indicating a need for more specimens to better understand the distribution and identification of morphological characters as well as a revision of the character states used for the lateral osteoderms of aetosaurians.

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PAINTED SHERDS IN THE PAINTED DESERT: A MULTISCALAR ANALYSIS OF A SHRINE SITE IN PETRIFIED FOREST NATIONAL PARK

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ABSTRACT — Lacey Point is a prominent butte rising above the Painted Desert in Petrified Forest National Park, containing a concentration of Ancestral Pueblo petro-glyphs, an extensive and diverse ceramic assemblage, and the fugitive remains of a small jacal structure on the butte's summit. Archaeologists interpret Lacey Point as a regional shrine site devoted to themes of hunting and fertility. To assess this inter-pretation, I reviewed the form and landscape context of shrine sites in the American Southwest and conducted a comparative study of Lacey Point's ceramics with three contemporary Painted Desert sites to determine if Lacey Point's ceramic assemblage is indeed disproportionate in its quantity and diversity. I determine the landscape context of Lacey Point is consistent with regional shrine sites and identify cupule and grinding slick features characteristic of devotional shrine features. I establish Lacey Point has a disproportionately large and diverse ceramic assemblage, with a deeper temporal span than previously understood. I conclude Lacey Point was a space designed for regional ritual gatherings, with a range of domestic and ceremonial activities taking place on site. Adopting a multifarious approach enables a more holistic understanding of land-scape iconography, imbedding petroglyphs within a greater network of interrelated archaeological features.

Keywords: Petroglyphs, Ceramics, Landscape Archaeology, Ritual, Pilgrimage.

INTRODUCTION

Stretching out across the north end of Petrified Forest National Park, the Painted Desert is a stark, strange, and imposing landscape of lurid clay badlands and fields of black petrified wood (Figure 1). Archaeological assessments of the Painted Desert are mostly limited to its peripheries, with large swaths of this landmark being *terra incognita* for archaeologists. While lacking the largescale habitations found elsewhere in the park, the material legacy of Ancestral Pueblo peoples is abundantly present in the Painted Desert. Within traditional indigenous belief systems in the American Southwest, landscapes were organized in accordance with central cosmological principles, with certain numinous places bridging the divide between this world and that of spiritual powers inhabiting the landscape (Fowles, 2009; Ortiz, 1969; Van Vlack, 2012; Young, 1988). These spaces familiarize the landscape, provide spaces for prayer and offering, and affirm people's sense of place in the world. Lacey Point (PEFO00574), located on the threshold of the Painted Desert, is a prominent petroglyph site embodying many characteristics of an ideologically organized ritual space. In the spring of 2022, a comparative study of Lacey Point's ceramics and reassessment of its landscape context was conducted to evaluate its potential as a space for staging ritual performance.

Lacey Point is a topographically prominent Ancestral Pueblo site, dating to the Pueblo II–Pueblo IV periods (CE 900–1450). Lacey Point contains a series of petroglyph panels structured around themes of fertility and hunting, paired with a concentration of thousands of ceramic sherds and other artifacts. This extensive artifact assemblage sharply contrasts with the remains of a small jacal structure atop the Lacey Point butte. Based on its deliberately themed petroglyph panels, dramatic placement on the landscape, and the seemingly inordinate amount and variety of ceramics for such a structurally small site, archaeologists interpret the site as a space for ritual performance. While previous studies (Hays-Gilpin, 2004; Potter, 2004; McCreery and Malotki, 1994; McCreery and McCreery, 1986; Slifer, 2000) speculate on specific meanings and associations attached to Lacey Point's petroglyphs, I believe this imagery is best understood through a more holistic examination of the site in the context of the greater Painted Desert cultural landscape.

To better evaluate the potential ceremonial nature of Lacey Point, I adopted a multifaceted approach combining artifactual analysis with the context provided through landscape theory. Specifically, I conducted a comparative ceramic analysis of Lacey Point with three other Painted Desert sites, selected for their variability in form and landscape setting. By comparing the ceramic wares of each site, I addressed the following research questions: Does the quantity and make-up of Lacey Point's ceramic assemblage stand apart from neighboring domestic and fieldhouse sites? Are ceramics at Lacey Point characterized by specific trade wares, suggesting symbolic ties with particular places or populations? Does Lacey Point possess ceramic indicators of ceremonial feasting events, specifically in the form of a higher ratio of painted serving vessels versus utilitarian storage/cooking vessels? How does Lacey Point compare to other suspected shrine sites in the American Southwest in its artifacts, features, and landscape context?

Answering these questions provides a fresh assessment of a complex cultural space in an understudied area of Petrified Forest National Park, while fostering a greater knowledge and appreciation of ritual landscapes in the American Southwest. The results of this ceramic analysis affirm the singular nature of Lacey Point's artifactual assemblage and clarify the temporal span of the site. The discovery of additional artifacts and modified rock features provides a more comprehensive understanding the activities performed at Lacey Point. Ultimately, this study demonstrates the utility of using multiple lines of contextual data for studying petroglyph sites and the difficulty of fitting multifaceted sites into preconceived typologies.

The Petrified Forest Cultural Landscape

Petrified Forest National Park preserves a long and diverse human history. Paleoindian and Archaic sites occur throughout the park, but ultimately represent a marginal footprint on the landscape. A proliferation of Basketmaker II–III (C.E. 0–700) pithouse villages mark the transition to a more sedentary lifestyle and adoption of agriculture, with Twin Buttes, the Flattop Site, and Sivu'ovi being some of the more prominent Basketmaker sites in the park. Ceramic production began in this period, consisting of Adamana Brown and Lino Gray (Hays-Gilpin and van Hartesveldt,



FIGURE 1. Overview of the Painted Desert landscape with park archaeologists descending through Triassic clay badlands.

(1998). Petrified Forest also appears ideologically diverse, containing sites reflecting an admixture of local and introduced ceremonial practices. Petrified Forest lies on the peripheries of the Chaco Phenomenon, sitting near the terminus of a series of great house and great kiva sites strung along the Rio Puerco of the West (Hays-Gilpin and Gilpin, 1999; Herr, 2001; Warburton and Graves, 1994). This includes a great kiva at McCreery Pueblo, located in the north section of the park. However, excavations revealed architectural and artifactual ties more consistent with communities to the south and west than with Chaco (Burton, 1993). The Mac Stod site is a probable great house on the eastern boundary of the park (Figure 2), with distinctly Chacoan architectural traits and jog-toed sandal petroglyphs associated with Chacoan identity (Bellorado, 2020). However, the broader impact of this outlier community on local petroglyph traditions appears limited, suggesting Chaco's ideological influence was limited on the people of Petrified Forest (Forton, 2022). To the northwest of the park, the Navajo Springs great house is characterized by a locally produced artifact assemblage, but possesses distinctly Chacoan architecture, with earthen berms and roads suggestive of formalizing and controlling the flow of human movement into the great house (Warburton and Graves, 1994). These ceremonial sites demonstrate the complex multicultural identity embodied in Petrified Forest.

Petrified Forest developed a profuse and complex petroglyph tradition during the Pueblo II–III periods. Subjects range from simple to intricate in their execu-

tion, suggesting a range of skill and purpose in their creation. Distinctive elements of the Petrified Forest region include complex textile designs, a menagerie of various animals, and figures with complex interior geometric decorations often wielding dance wands or banners. Sexed figures are not uncommon, with female figures appearing reserved for specific contexts (McCreery and Malotki, 1994: 34). Several recurring tableaus suggest deliberate thematic compositions, including the Mother of Game Animals, a figure from Hopi oral traditions identified with the Lacey Point site (McCreery and Malotki, 1994). Pictographs are exceptionally rare at Petrified Forest, with none known in the Painted Desert portion of the park.

The Pueblo IV Period witnessed the aggregation of Petrified Forest populations into large-scale villages at Wallace Tank Pueblo, Puerco Pueblo, and Black Axe Pueblo. These communities were oriented around plazas and fully engrossed in the emergent Katsina ideology. New styles of painted ceramics include Maverick Mountain polychromes, Jeddito Yellow Ware, and Zuni glaze wares (Hays-Gilpin and van Hartesveldt, 1998). Katsinas and related imagery appear in petroglyph panels associated with Puerco Pueblo and a few other isolated locales in the park. Pueblo IV sites in the Painted Desert are rare, with only a few petroglyph panels depicting potential katsina masks and figures (Figure 3). By C.E. 1400 populations at Petrified Forest migrated to neighboring regions, with the area remaining an important ancestral landscape for multiple descendent Native communities.



FIGURE 2. Looking south through the remains of the Mac-Stod great house.

Location and Environment of Lacey Point

Lacey Point is located in the north end of Petrified Forest National Park, set on an isolated landform jutting out from a wide terrace between the mesa rim and valley floor of the Lithodendron Wash. Steep terrain effectively reduces access to a narrow saddle on the eastern flank of Lacey Point. Approaching the site from any other direction is feasible but requires a difficult climb up sheer and unstable badlands. Rising up from the point is a small butte, with slopes covered in white sandstone boulders (Figure 4). At the southern and eastern base of the butte are two depressions forming natural amphitheater-like spaces. The top of the butte is flat and measures 10 x 5 m.

Lacey Point occupies a unique transitional zone between the mesa top and valley floor, characterized by a mixture of Triassic clay badlands, black petrified wood outcrops, small sand dune ridges, and sheer sloped box canyons. Vegetation is limited to short grasses, ephedra, and cacti. In a landscape of gray and red, Lacey Point stands out as a pillar of white looming above the valley floor. From the summit of Lacey Point, one takes in a panorama of the Painted Desert, with clear viewsheds to Pilot Rock and Pintado Point. Site density on the surrounding terrace is relatively low, consisting mainly of isolated Pueblo II–III petroglyph panels and ubiquitous petrified wood lithic scatters. The Boundary Site located to the west of Lacey Point comprises the largest documented concertation of petroglyphs in the park, but its potential relationship to Lacey Point remains uncertain. Multiple pueblo roomblocks and fieldhouse sites occupy the mesa rim to the south of Lacey Point.

Previous Archaeological Research at Lacey Point

This paper builds upon nearly four decades of archaeological research at the Lacey Point site. Much of this research focuses on the site's 28 petroglyph panels concentrated on the southwest side of the butte and varying greatly in their content and complexity. In one of the first formal assessments of the site, Pat and Jack McCreery (1986) conducted an ethnographically informed interpretation of a striking panel centered around a large figure with raised hands, splayed legs, and exposed vulva (Figure 5). The figure is flanked by circular disks and accompanied by quadrupeds with raised tails, birds, a bow and arrows, and a fluteplayer. On the same panel are two pairs of human feet, with the second toe exaggerated to resemble a phallus. The sexually receptive posture of the female figure and accompanying quadrupeds, phallus-like toes of the feet, and fluteplayer were all identified as fertility themed elements. Concurrently the game animals, and bow and arrows were elements suggestive of hunting themes.

Seeking an ethnographic figure embodying both themes of fertility and hunting, McCreery and McCreery (1986) attributed the large female anthromorph to Tuwabontumi, the Mother of Game Animals figure from Hopi oral traditions. This powerful and potentially dangerous figure is responsible for the propagation of game animals and offerings to her are required for a safe and successful hunt. Her home is said to be in the Little Colorado River Valley to the west of Petrified Forest. McCreery and Malotki (1994) identified further Mother of Game Animals depictions throughout the greater Little Colorado region, classifying the figure as a diagnostic element of a locally



FIGURE 3. Isolated Pueblo IV period petroglyph located in the Painted Desert portion of Petrified Forest National Park



FIGURE 4. Overview of the Lace Point butte from its southern approach.



FIGURE 5. The Mother of Game panel located on the western slope of the Lacey Point butte.

developed petroglyph tradition.

Pat and Jack McCreery (1986) interpreted Lacey Point as a shrine site where hunters made offerings and performed rituals to receive the blessing of the Mother of Game Animals. In the ensuring decades, archaeologists continue to thematically associate Lacey Point with fertility and hunting. Potter (2004) describes Lacey Point as a space where intertwined metaphors of hunting and sexuality were experienced and embodied. The Mother of Game Animals petroglyph graphically transformed the site into a stage for performances of male gender roles and asserted the spiritual potency of Lacey Point. Slifer (2000) includes Lacey Point in his overview of fertility imagery in the American Southwest and Hays-Gilpin (2004:141) cites Lacey Point when describing female personages depicted in petroglyphs from Pueblo oral traditions. She cautions though that in Puebloan iconography, almost anything can serve as a 'fertility" symbol, complicating the identification and interpretation of fertility themed sites. Furthermore, Hays-Gilpin notes that while the Lacey Point imagery suggests the supplication of the Mother of Game Animals deity by male hunters, no such ceremony is recorded in the ethnographic literature.

While the Mother of Game Animals panel is prominently displayed, most petroglyphs at Lacey Point are hidden among the boulders, with some squeezed into crawl spaces barely able to fit a single person (Figure 6). These less visually prominent panels contain anthromorphs, spirals, bighorn sheep, lizards, elk or deer, a centipede, fluteplayers, rectilinear designs, and circular geometrics. The potential ritual function of these other panels remains largely unassessed. McCreery and McCreery (1986) suspected a large spiral petroglyph was a solstice marker, but their subsequent observations failed to note any interplay of light and shadow across the glyph. Solstice calendar petroglyphs are documented at Petrified Forest, including a publicly visible summer solstice marker at Puerco Pueblo, but none are known from the Painted Desert portion of the park.

Lacey Point's petroglyphs are visually striking, but their functional relationship to ritual actions performed on the site comes into focus when framed with the site's extensive ceramic assemblage. In the first full-scale documentation of the site in 1991, archaeologists from the Western Archeological and Conservation Center (WACC) were struck by the size and scope of the site's trash scatter, estimating it contained thousands of ceramic sherds and lithic flakes, including a prominent amount of trade wares. Based on a large number of polishing stones, WACC archaeologists concluded ceramic production occurred on the site. Lithic debitage, mostly in the form of secondary black petrified wood flakes, is consistently intermixed with the ceramic assemblage. There are no major naturally occurring black petrified wood deposits on site, indicating the material was likely collected from outcrops along the base of the mesa to the south. Other artifacts observed during my own fieldwork at Lacey Point include over twenty manos and metates, a piece of raw turquoise, a quartzite hammerstone, the tip of a petrified wood projectile point, shaped sherd discs, a probable shaped sherd gaming piece, and polishing stones. Small burnt faunal bone is scattered throughout the midden area on the east side of the site.

WACC archaeologists identified the remains of a small two-three room jacal structure atop the butte, discerned by upright slab alignments and scattered daub (Figure 7). Such structures are not un-

common at habitation sites in Petrified Forest, but in describing Lacey Point WAAC archaeologists note the lack of easy access to reliable water sources, arable land, or quality lithic material. The juxtaposition of the site's disproportionately large ceramic assemblage with a lack of clear habitation structures is cited as further evidence of ritual activity at Lacey Point. McCreery and McCreery (1986) believed Lacey Point butte was too small and exposed for habitation and noted a lack of quality structural stone on the site. Traces of fire atop the butte were interpreted as evidence of bonfires used to signal the start of communal hunting events, with the ceramic assemblage seen as material offerings to a hunting shrine. Using diagnostic ceramics, Potter (2004) dates the site primarily to the Pueblo IV period, linking Lacey Point to the aggregated communities of Puerco Pueblo and Wallace Tank Pueblo in the south end of the park. Citing the high ratio of Jeddito Yellow Ware at these communities, Potter materially links Lacey Point to Hopi oral traditions of the Mother of Game Animals. Nestleroth (2017) conducted a preliminary comparison of suspected shrines at Petrified Forest based on a self-selected set of criteria attributed to shrine sites, concluding Lacey Point was a significant shrine.

Collectively Lacey Point is interpreted as a ceremonial space devoted to themes of fertility and hunting. Thematically charged petroglyphs created a space where rituals related to hunting and male sexuality were performed, with offerings producing an extensive ceramic assemblage. This understanding of Lacey Point does not seriously integrate the presence of the summit jacal feature and the implication of it being some form of habitation structure. The presence of burnt faunal remains, food processing implements, ceramic polishing stones, and lithic debitage suggest a range of activities occurred at Lacey Point. Alternative scenarios for Lacey Point's ceramic assemblage must be assessed, including the disposal of standard domestic waste or the mass refuse from group gatherings. The extensive literature surrounding ceremonial spaces and feasting events in the American Southwest creates a contextual framework for analyzing Lacey Point.

Ceremonial Spaces and Gatherings in the American Southwest

Ceremonially structured spaces have a deep history in the American Southwest, holding continued importance for descendant Native communities. Pueblo peoples have long used plazas and kivas as staging grounds for ceremonial performance, but ritual spaces take on a variety of forms found within a wide range of locations and contexts. Purposefully placed at sanctified places on the landscape, shrines are destinations for pilgrimage, offering, prayer, and initiation. Shrine features align landscapes to cosmographic principles, helping familiarize spaces and foster people's sense of geographically anchored identities.

People develop a sense of place through generations of social engagement with a landscape. Out of a blank canvas, people draw forth a landscape by selectively and subjectively assigning certain landmarks with cultural and spiritual significance (Basso 1996). Shrines and other ceremonial spaces are key features in this process, simultaneously delineating boundaries on the physical and cosmographic landscape. Examples of this are seen in the system of shrines surrounding Eastern Pueblo villages oriented to the cardinal directions and



FIGURE 6. Example of petroglyphs at Lacey Point squeezed into a narrow gap between boulders.



FIGURE 7. Upright slabs marking the foundation of a small jacal structure atop the Lacey Point butte.

used to replicate the cosmic structure of the Pueblo world (Fowles, 2009; Ortiz, 1969). Ortman (2009) reports on similar shrine landscapes at the Castle Rock pueblo in southwestern Colorado, pushing this practice back to at least the C.E. 1200s. Similar practices likely delineated socio-ideological boundaries and ties between Chacoan communities, through an intervisible network of great houses and shrines placed atop prominent landmarks. This network may have facilitated communication between great house communities and symbolically anchored them to Chaco Canyon (Van Dyke, 2017; Van Dyke et al., 2016). More than just places of worship and devotion, shrines are world building nodes at the intersection of cultural spaces.

Shrines occur in a variety of contexts but are often simple in form and construction. Pueblo advisors point out that many shrines are so simple in construction that they may easily be overlooked by archaeologists (Colwell-Chanthaphon and Ferguson, 2006; Kuwanwisiwma and Ferguson, 2004). Shrines may be as simple as a pile of stones or upright rock slab, with some encompassing landscape features with no obvious cultural modifications, such as mountain peaks, springs, and caves (Ferguson et al., 2004; Fewkes, 1906:366). More than the structures themselves, shrines are defined by the liminal spaces they occupy. Various forms of shrines may occur together, forming a package of ritual features replicated across the landscape. Some shrines mark places for resource collection, including salt, plants, pigments, or water from sacred springs (Titiev, 1935;Van Vlack,

Van Vlack, 2012). Often shrines delineate the boundary between sanctified spaces and signal numinous locations on the landscape where spiritual power resides (Fowles, 2009; Huffman and Earley, 2017; Ortiz, 1969; Stoffle et al., 2015; Van Vlack, 2012; Young, 1988). Often access to these sites follows prescribed paths, where human movement is purposely choreographed and restricted (Snead, 2002; Fowles, 2009; Van Vlack, 2012).

Rock imagery is often directly associated with ceremonial spaces in the American Southwest. Intrinsically bound to the landscape, petroglyphs and pictographs transform spaces by topographically manifesting ideologies. While exact meanings are often unclear, landscape context preserves the impact of rock motifs on the people who created, encountered, and interacted with them. This is illustrated by rock images placed along formal trails used to inform, direct, commemorate, and consecrate people's journeys (Darling, 2009; Huffman and Earley, 2017; Snead, 2002; Van Vlack, 2012; Whitley, 2008; Weiner, 2023). On the Hopi Salt Pilgrimage Trail to the northwest of Petrified Forest, the Tutuveni shrine is adorned by hundreds of clan symbol petroglyphs commemorating generations of Hopi men pilgrimaging to the Grand Canyon (Titiev, 1935). Rock imagery also pictorially delineates the boundaries between different social and spiritual spaces. Historically petroglyphs marked shrines on the Hopi Mesas and signified which spiritual beings inhabited the sites (Fewkes, 1906), echoing interpretations of petroglyphs dedicating Lacey Point to the Mother of Game Animals. Similar practices of rock imagery defining the boundaries of ceremonial spaces are reported from Rio Grande pueblos (Jeancon, 1929; Ellis, 1974:108), Southern Paiute (Van Vlack, 2012), and Hohokam (Russel et al., 2009).

Additional features associated with ritual spaces include grinding slicks, bedrock mortars, and cupules. Grinding slicks and bedrock mortars were used for processing plants or pigments used in rituals (Fowles, 2009; Huffman and Earley, 2017; Stoffle et al., 2015; Van Vlack, 2012), while cupules were formed to collect rock dust from sacred sites (Ford and Shapiro, 2016). Rock surfaces housing benevolent spirits were often chosen for cupule production, with the rock dust rubbed onto the body or ingested for medicinal purposes. Fowles (2009) reports the main entrance to the ancestral Tiwa pueblo at T'aitona was flanked by purposefully positioned cupule covered boulders. These boulders not only physically channeled the movement of people into the pueblo but elicited a ritual response as evidenced by the cupules. Material remains of activities performed at shrines are often sparse, with ethnographic accounts describing offerings of perishable feathers and prayers sticks (Fewkes, 1906; Titiev, 1935). Other offerings may be lithic flakes, igneous rock, colorful stones, and petrified wood. Shrines with deposits of ceramic artifacts are also well documented (Hough, 1907:19; Stoffle et al., 2015; Till, 2017; Van Vlack, 2012; Weiner, 2023).

Shrines are not the only destinations for pilgrimage and religious expression. Commensal politics is the structured act of communal feasting centered around fostering social relationships beyond the family (Dieter and Hayden, 2001). Routine supra-communal gatherings for feasting, exchange, and public performance are well documented in the American Southwest archaeological record. Ceremonial feasting is known to create large amounts of ceramic refuse,

although material remains of these events are not uniform across different communities, with signatures of public gatherings being context dependent. Rather, traces of public events stand out in quality or quantity from the local archaeological assemblage (Wills and Crown, 2004:155). The characteristic traces of feasting in one context, may be standard domestic remains in another.

A ceramic indicator of public ritual is the bypassing of locally produced ceramics for imported alternatives. Ceramic vessels and other goods from distant places may become symbolic representations of these locales. Possessing objects linked to nonlocal places or people may imbue prestige or symbolic legitimacy to public rituals. A hallmark case of this was observed at Pueblo Alto, where nonlocal Chuskan ceramics were systematically deposited in the great house's trash mound. Symbolic ties to the Chuska region may have necessitated the importation of Chuskan vessels for communal events (Toll, 1985). Another example is the continued use and exchange of San Juan Red Ware vessels in feasting events, even though local populations outside of southeast Utah were capable of producing their own redware vessels. This suggests a specific association between San Juan Red Ware ceramics and ritual feasting traditions adopted by communities outside southeast Utah (Spielmann, 2002). Similarly, Graves and Spielmann (2000) link the spread of imported glaze-painted ceramics among Salinas district Pueblo IV communities with public ceremonial feasting events. These examples demonstrate how the power of place may shape the materials used in public events. Serving vessels are highly visible objects, with the power of place requiring vessels to possess a particular style produced in specific locations.

Blinman (1989) found Pueblo I roomblocks associated with ritual pit structures contained smaller cooking jars and a higher ratio of serving bowls to cooking vessels. This suggests a division of labor between different households/spaces, with some locales emphasizing the serving of food, with other households responsible for food preparation. Potter (2000) similarly found communal feasting occurred in large Pueblo IV period communities of the El Morro region, with large sites possessing ritual plazas containing a higher ratio of turkey bones and cooking pots for feasts. One indicator of feasting activities is of course food remains, with Potter (1997, 2000) suggesting increases in rabbit consumption at McPhee Village reflected communal feasting, as rabbit hunting was historically a Puebloan communal activity prior to certain feasts.

In the larger context of sacrosanct spaces in the American Southwest, Lacey Point bears multiple features of a ceremonial shrine. The site's elevated and visually striking placement on the landscape, the presence of ideologically charged petroglyphs, and the physically restricted access to the site are all documented facets of shrine complexes. However, the large ceramic assemblage is less consistent with documented shrine spaces. Perhaps Lacey Point was a meeting ground for public feasting events producing large quantities of refuse. If Lacey Point was a site for formalized feasting events, the ceramic assemblage should stand out in quality/quantity from the local archaeological assemblage or be characterized imported ceramics from a particular locale.

METHODS

To address the nature of the Lacey Point site I conducted a systematic survey of the site's surface ceramic assemblage. Lacey Point's conspicuous ceramic assemblage and fugitive architectural remains are repeatedly cited as evidence of the site being a type of ceremonial shrine. To determine if Lacey Point's ceramic assemblage supports these interpretations, I compared the site's ceramic assemblage to three contemporary sites located within a mile of Lacey Point. Each site was chosen for possessing a different combination of structure types and landscape settings See Table 1 (Appendix), for a breakdown of the architecture, landscape setting, and expected ceramic assemblage of each site. Should Lacey Point artifactually stand apart from neighboring domestic and fieldhouse sites, its singular status as a ceremonial site appears more probable. Pilles (1978) conducted a similar study comparing the ceramic assemblages of Sinagua fieldhouse and domestic structures in the Flagstaff area. While initially expecting fieldhouses to contain a lower proportion of trade wares than domestic sites, Pilles determined the percentage of non-local vessels was actually broadly consistent across both sites. Rather than the frequency of occurrence, the number of ceramic trade ware types was found to be lower in fieldhouses and higher in domestic sites. Permanent habitation sites were also found to contain a greater variety of artifact types reflecting of a greater range of activities performed in these domestic spaces. Fieldhouse sites conversely had a limited number of artifact types, with a greater emphasis on mealing tools. This provides a framework to assess the functions of all four sites through a comparative ceramic analysis.

This analysis will also assess the possibility of Lacey Point being the staging ground for largescale feasting events. Hayden (2001:40) suggests a greater number of decorated food-serving vessels is probable evidence of largescale feasting events. Additionally, Blinman's (1989) study of the differential occurrence of ceramic vessels at McPhee Village ritual pit structures provides a framework for assessing the Lacey Point ceramic assemblage. A higher ratio of serving bowls to utilitarian jars and a higher ratio of imported vessels would differentiate Lacey Point as a potential site for communal feasting events.

At each site I placed 1 x 1 m sampling units in linear rows at three-meter intervals. Each unit was assigned an identification number with its geolocation marked. Within each unit I tallied and typed the sherds, using the regional ceramic typologies devised by Colton (1953) and refined by Hays-Gilpin and van Hartesveldt's (1998) ceramic analysis of the Chambers-Sanders Trust Land to the east of the park. For each sherd I noted the ware, type, vessel form, vessel part, and any surface modifications. This data captures the temporal range of each site, the ratio of serving versus storage/cooking vessels, and the frequency of different trade wares.

Sampling units were placed in different sections of each site to capture any potential disparate distribution of ceramics. At Lacey Point sampling units were placed within the midden on the east slope of the site, the two depressed areas on the south side of the site, the petroglyph panel concentration on the west side of the site, and among the butte's summit jacal structure. Lacey Point receives some public visitation, resulting in multiple "museum" piles of large and

distinctive sherds. These piles were excluded from sampling due to the disproportionate number of decorated serving bowl sherds. The other three sites lack visitor made disturbances. Due to differing erosional condition on each site, I do not depend on ceramic totals as a measure of activity. Lacey Point lacks substantial sediment deposition, likely creating a larger surface assemblage of artifacts than would be found in other erosional settings. PEFO00608 is located within an area of grass anchored dunes, while PEFO00551 and PEFO00575 have combinations of dunes, exposed playa, and clay badlands. For these reasons, the percentage of various ceramic wares are the main measure for interpreting and comparing site functionality.

RESULTS

A total of 311 ceramic sampling units were placed across the four sites, capturing nearly a thousand individual sherds. I map the distribution of ceramic types from graywares/brownwares (Appendix; Table 2), redwares/polychromes/yellowwares (Appendix; Table 3), and whitewares (Appendix; Table 4) across the four sampled sites. Further breaking down the ceramic makeup of each site reveals differences in the average sherds per square meter (Appendix; Table 5), percentage of wares across the four sites (Appendix; Table 6), number of ceramic types per site, (Appendix; Table 7), percentage of vessel forms (Appendix; Table 8), and percentage of regional whiteware types (Appendix; Table 9). Comparing the ceramic makeup of each site provides new context for Lacey Point's relationship within the Painted Desert cultural landscape. In the course of sampling Lacey Point, additional artifacts and features were identified, providing fresh data for revaluating the activities conducted at Lacey Point.

Lacey Point (PEFO00574)

55 ceramic sampling units were installed at multiple sections of Lacey Point, documenting a total of 651 sherds creating an average of 11.8 sherds per sample unit (Appendix; Table 5). Lacey Point has a substantial and diverse ceramic assemblage, dominated by locally made Puerco Valley Gray Ware (Appendix; Table 2), but with the greatest variety of whiteware and redware types of any sampled site (Appendix; Table 7). Whitewares at Lacey Point are characterized by a wide variety of regional traditions, with a slightly higher number of Little Colorado sherds (Appendix; Table 9). Notably, one striking Tularosa Black-on-white jar sherd depicts a macaw (Figure 8). Lacey Point has the lowest percentage of redware sherds of the four sites, but this is slightly offset by having the second highest ratio of polychrome sherds and the only site possessing Jeddito Yellow Ware (Appendix; Table 6). The vessel forms at Lacey Point indicate a combination of cooking, storage, and serving vessels similar to those of the roomblocks at PEFO00575 and PEFO00608 (Appendix; Table 8). Compared to the other sampled sites Lacey Point has a higher quantity of vessels being consumed, characterized by a dominance of local greyware jars and by far the most regionally diverse assemblage of painted vessels.

PEFO00551

The architectural rubble and artifact scatter at PEFO00551 form a relatively



FIGURE 8. A Tularosa Black-on-White jar body sherd depicting a macaw, found at Lacey Point. Once square on the scale equals one centimeter.

small site area, requiring fewer sampling units to cover the breadth of the site. 17 sampling units documented 41 sherds for an average of 2.41 sherds present per sample unit (Appendix; Table 5). The assemblage is characterized by a low-density scatter, composed mainly of local grayware jars and a small selection of painted jars and bowls (Appendix; Tables 7 and 8). The ceramics are evenly distributed across the site, with no clear concentrations. The small structure and lack of regional diversity in the ceramic assemblage of PEFO00551 is consistent with ancillary fieldhouse sites (Pilles 1978).

PEFO00575

A total of 45 sampling units were placed across two pueblo roomblocks, capturing a total of 52 ceramic sherds, forming an average of 1.16 sherds per sample unit (Appendix; Table 5). Sherds are mostly on the slopes below the pueblos, but the density of artifacts is seemingly low for a site with two multiroom habitation structures. The assemblage consists mainly of local grayware jars, with the remaining consisting primarily of Little Colorado White Ware and White Mountain Red Ware bowls (Appendix; Tables 6, 7, and 8). Outlying vessel forms are a single shaped sherd disc and a dipper. While sites with habitation structures may be expected to have a greater quantity and variety of ceramics, PEFO00575 has a ceramic assemblage closer in quantity and content to the fieldhouse at PEFO00551.

PEFO00608

A total of 50 sampling units were placed across the site's exposed slope below the mesa rim, within the pueblo roomblock, and on the floodplain to the south of the pueblo. A total of 221 sherds were identified forming a concentration of 4.42 sherds per unit (Appendix; Table 5). Local grayware jars form the bulk of the assemblage, with white and redware vessels forming roughly a quarter of the assemblage (Appendix; Tables 6 and 7). The majority of the whiteware vessels are jars, with Little Colorado types being the most common, followed by lesser amounts of Cibola and Tusayan types (Appendix; Tables 8). A single Zuni glazeware sherd was also found, indicating limited site usage in the Pueblo IV period. Redwares are evenly split between local types and imported White Mountain Red Ware, including four polychromes, along with a single Winslow Orange Ware. The architecture and artifact assemblage at PEFO00608 is consistent with Pueblo II–III habitation sites found throughout the Petrified Forest region.

ASSESSMENT OF RESULTS

Comparing the four sampled ceramic assemblages reveals a mixture of commonalities and distinctions reflective of each site possessing a singular combination of architectural and landscape traits. Lacey Point and PEFO00551 possess minimal architecture, while PEFO00576 and PEFO00608 contain multiroom pueblo roomblocks. Lacey Point and PEFO00576 are located on the transitionary bench descending into the Painted Desert, while PEFO00551 and PEFO00608 are located on the mesa top above. In spite of differences in setting and architecture, there are shared practices in ceramic consumption across the four sites. Examining Table 2 (Appendix) locally made Puerco Valley Grayware jars are ubiquitous, with utilitarian vessels making up the bulk of the assemblage on all four sites. Whiteware vessels comprise 15–20% of each site assemblage, showing a consistent pattern of deposition. Similarly, redwares demonstrate a narrow range of consumption at 9.5–14%. Brownwares and polychromes are present in consistently marginal amounts. The proportion of various ceramic wares is consistent across all four sites, suggesting this is not a factor in differentiating site function.

Diverging percentages of vessel forms may be a better trait for understanding site function, as seen in Table 7 (Appendix). Jars are most common, but PEFO00551 has a notably higher proportion of 88%, with the other sites ranging between 70–77%. Conversely PEFO00551 has the lowest ratio of bowls (9.76%). This is consistent with PEFO00551 being a fieldhouse, where storage was the primary focus. Lacey Point is architecturally similar to PEFO00551 but has percentages of jars (73.85%) vs bowls (21.23%) similar to the two pueblo roomblock sites (PEFO00576 and PEFO00608). Here the singular nature of Lacey Point begins to emerge, possessing a higher proportion of decorated serving bowls than would be expected for a small fieldhouse size structure.

Lacey Point also diverges in the sheer variety of ceramic types, with 36 identified types compared with 9 (PEFO00551), 10 (PEFO00575), and 20 (PEFO00608). Little Colorado vessels were the most frequent whitewares on all

four sites, but Lacy Point has the highest percentage of Tusayan and Cibola whitewares, suggesting Lacey Point had broader regional ties than the other three sites. Additionally, Lacey Point contains four sherds of Jeddito Yellow Ware, likely representing offerings left by pilgrims returning to the site during the Pueblo IV Period.

The density of ceramic sherds is where the greatest divergence is seen between the four sites. Lacey Point has a mean of 11.8 sherds per sample unit, while the other three sites have means between 1.15–4.41 sherds per sample unit (Appendix; Table 2). Whereas the other three sites have no sampling units exceeding twenty sherds, a single sample unit at Lacey Point contained over sixty sherds. However, as previously mentioned this disproportionality high artifact density is likely partially reflective of more active erosional conditions at Lacey Point.

Interpreting the Lacey Point Site

The comparative ceramic study singles out Lacey Point for being an architecturally small site with a large number of decorative serving vessels deriving from a wide array of regional sources. Of the three sites, Lacey Point's ceramics most closely resemble the assemblage at PEFO00608, despite stark differences in setting and architecture. This validates previous assertations of Lacey Point's ceramic assemblage being distinctly large and diverse. Identifying the cultural processes responsible for this unique ceramic composition requires a reexamination of the other artifacts and features forming the Lacey Point site.

The diverse origins of Lacey Point's ceramics may hint at supra-communal feasting events, but the percentage of serving vessels is not appreciably higher than the neighboring pueblo roomblock sites. In the midden area a few jar sherds show signs of burning, but the majority exhibit no clear signs of use-wear. Food preparation may be reflected by over twenty manos and metates crafted from multiple types of sandstone concentrated around the summit jacal structure. Large numbers of grinding implements are characteristic of field house sites (Pilles, 1978), but the quantity and diverse origins of Lacey Point's ceramics are uncharacteristic for a field house. Burnt faunal remains were observed in the midden area, appearing to be mostly from small mammals and birds, however there are no discernable hearths located on the site. All together there is mixed evidence for the importance of food preparation and consumption at Lacey Point.

Evidence of food preparation and consumption is not a smoking gun for feasting though. The distribution of the ceramics across the site is perhaps more telling of the activities taking place on the site. The bulk of the ceramics are found on the eastern slope, below the remains of the jacal structure and intermixed with burnt faunal remains, lithic debitage, groundstone tools, and other artifacts. Collectively the placement and contents of this assemblage suggest a domestic midden typical of habitation sites in the park. Rather than being mounded around the natural amphitheaters at the base of the butte, the refuse is disseminating down from the top of the butte, where only a small group of people could comfortably gather. As evidenced by the distribution of artifacts, activity at Lacey Point was concentrated within and immediately around the jacal structure. While ceremonial meals may still have occurred at the site, largescale feasting events do not appear a reasonable explanation for Lacey Point's artifact

assemblage.

If not a staging ground for unifying feasting events, could Lacey Point still be a hunting shrine to some figure similar to the Hopi Mother of Game Animals? Such interpretations equate the large ceramic assemblage with offerings tied to devotional activities at the site's petroglyphs on the west side of the site. The artifactual evidence does not clearly support this theory, with only eight sherds found across ten sampling units among the petroglyph boulders. Interaction with the petroglyphs seemingly did not produce a substantial deposition of ceramics. McCreery and McCreery (1986) cite two projectile points on the site as further evidence of Lacey Point being a hunting shrine. However, projectile points are found in a variety of site contexts within Petrified Forest, making this line of evidence tenuous at best.

Another potential line of ritual evidence proposed by Jack and Pat McCreery (1986) was Lacey Point being a solar observatory used to track summer solstices and equinoxes. Using the solar tracking application Sun Seeker, I examined the rise and setting location of the sun during the solstices and equinoxes from multiple prominent locations at Lacey Point. I found the sun does not rise or set near any distinctive points on the landscape during any of the solstices or equinoxes. This observation does not rule out astronomical phenomenon being potentially significant to the character of Lacey Point but may temper speculations of the site being a solar observatory.

Clearer evidence of ritual activity at



FIGURE 9. Grinding slick on a boulder (marked by arrow), in front of Mother of Game petroglyph panel.

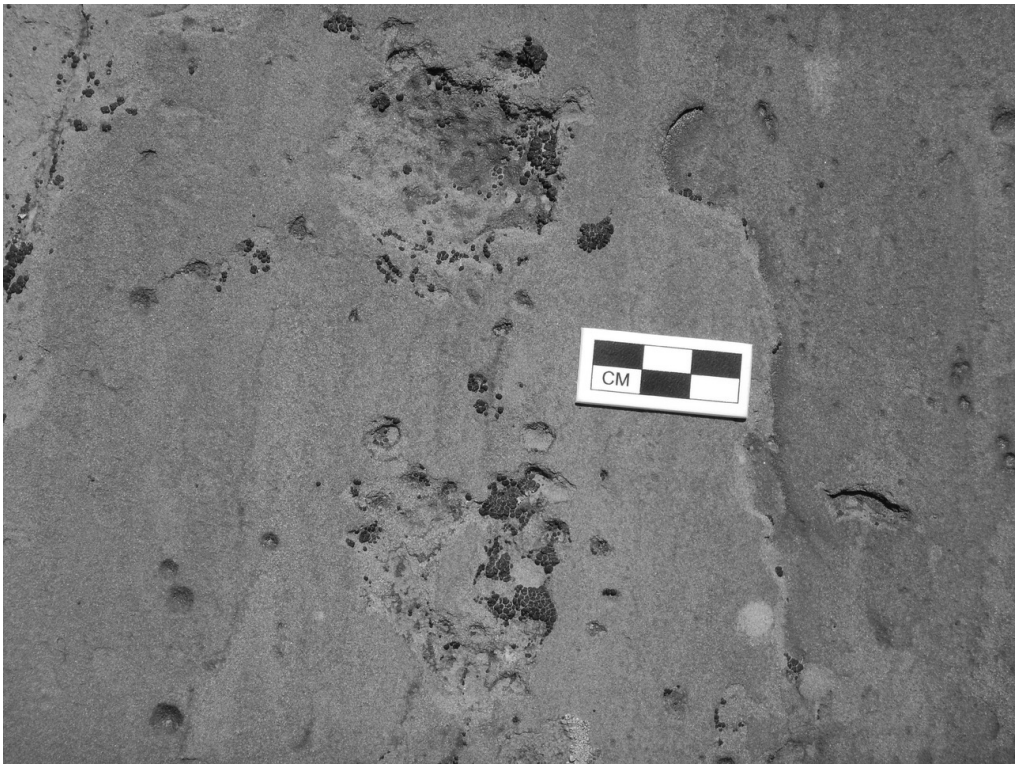


FIGURE 10. Pair of pecked cupules documented near the entrance to Lacey Point. One square on the scale equals one centimeter.

Lacey Point. I found the sun does not rise or set near any distinctive points on the landscape during any of the solstices or equinoxes. This observation does not rule out astronomical phenomenon being potentially significant to the character of Lacey Point but may temper speculations of the site being a solar observatory.

Clearer evidence of ritual activity at Lacey Point is the discovery of four previously undocumented polished slicks on sandstone boulders surrounding the Mother of Game Animals panel (Figure 9). These slicks are mostly rendered onto vertical or otherwise steeply angled surfaces, making them impractical for food preparation. More likely these were used to create and collect rock dust from a spiritually potent site, as ethnographically documented at other shrine sites in the American Southwest (Ford and Shapiro, 2016).

Another potential ritual feature identified by this project was a small cupule slab (Figure 10). This slab is on a slanted boulder face with a smoothed prepared surface. The feature is subtle, with only a few small cupules and areas of random pecking but is located near the only entry point to the site. Fowles (2009) describes a similar placement of rock cupules flanking the formal entrance into the ancestral Tiwa pueblo of T'aitona, with other cupule boulders and bedrock grinding slicks marking shrines cosmographically arranged across the local landscape. With a naturally restricted entry funneling people into the site, this cupule slab may mark the threshold of a sanctified space in the

Painted Desert. While cupule shrine features are typically more heavily used, its placement at the natural entry point to the site appears intentional. Cupules are also reported to be used in grinding pigments and preparing paints, suggesting an additional ritual function for this feature (Dart and Reed, 2020). Together the cupule slab and vertically aligned grinding slicks suggest some forms of devotional activities were undertaken at Lacey Point.

The reassessment of Lacey Point's ceramics produces a maximum temporal span of C.E. 400–1400. However, variations in the quantity of different ceramic types strongly suggests usage of the site was not continual, with three distinct periods of site usage discernable in the ceramic assemblage. First is a light Late Basketmaker III–Early Pueblo I (C.E.550–850) presence marked by two Lino Black-on-white bowl rim sherds and potentially some of the plain gray jar sherds. The bulk of the ceramic assemblage derives from the Pueblo II–III period, consistent with the style of the site's petroglyphs. The narrowest temporal span accounting for all the Pueblo II–III whiteware and redware types present on the site is C.E. 1100–1225. The predominance of Puerco Valley Grey Ware vessels (Appendix; Table 2) indicates strong ties to the local population of the Petrified Forest region, while the diversity of redware and whiteware types (Appendix; Table 7) suggest a greater degree of regional interaction. Last are seven sherds from the Pueblo IV period indicating a limited site use beyond C.E. 1300. While Pueblo IV period Jeddito Yellow Ware sherds were only found at Lacey Point, they are in too marginal amounts to clearly support Potter's (2004) interpretation of Lacey Point being specifically associated with Puerco Pueblo and by extension the Hopi Mesas.

The greater artifact assemblage indicates a range of activities took place at Lacey Point. Polishing stones may reflect ceramic production and thousands of locally derived petrified wood and yellow chert flakes attest to the production of flaked stone tools. A piece of raw turquoise was also observed, although no debris from jewelry production were observed, indicating this was more likely left as an offering. Gambling and other games are well documented in the American Southwest, with visually distinctive sherds shaped into discs and oblong forms found at Lacey Point possibly functioning as gaming pieces (Riggs 2016). Weiner (2018) writes gambling in the American Southwest was typically used to mediate social relationships between socially distinct populations. This correlates with the site's diverse ceramic assemblage, portraying Lacey Point as a meeting ground for disparate social groups. Based on the site's restricted access and small architecture, Lacey Point may have been reserved for a select group of religious specialists. While the nearby McCreery Pueblo great kiva functioned as a public ceremonial space for the local Petrified Forest population, Lacey Point may represent a socially restricted pilgrimage site, possibly reserved for ritual devotions to a Mother of Games figure associated with fertility and/or hunting.

An alternative interpretation worth addressing is Lacey Point being a defensive redoubt for the larger dispersed pueblo community, as proposed by WACC archaeologists during a 2010 condition assessment of the site. Access to the site is restricted and the elevated butte offers an impressive viewshed and defensive advantage over the surrounding

landscape. However, there is no defensive architecture on the site and no strong evidence of chronic violence afflicting the people of Petrified Forest in the Pueblo II–III period. Additionally, the temporal span of ceramics dating from the Basketmaker III–Pueblo IV period suggests Lacey Point held significance well beyond the need for a pragmatic defensive shelter. Finally, this interpretation does not account for the higher ratio of trade wares at the site and the deliberately themed petroglyph panels.

Recognizing a Distinct Form of Elevated Ritual Space

Lacey Point emerges as a multifaceted site, standing out on the Painted Desert cultural landscape in its prominent placement and unusually large and diverse ceramic assemblage. While architecturally approximating a fieldhouse (PEFO00551), Lacey Point's ceramic assemblage exceeds neighboring pueblo roomblock sites (PEFO00575 and PEFO00608) in size and scope. This may support the long-speculated belief Lacey Point is a major shrine site, but the predominance of grayware jars and the non-ceramic contents of the midden are more indicative of typical household refuse. However, Lacey Point's location appears inconducive for a habitation site. The top of the butte is exposed to the elements and arable land on the surrounding bench appears limited. Pueblo habitations are instead concentrated along the mesa rim to the south, with PEFO00576 containing one of the larger roomblocks. Significant habitation sites are rare within the Painted Desert itself, with PEFO00608 being an exception to this trend. (The comparatively small ceramic assemblage at PEFO00608 suggests though a potentially limited scope of habitation). Through a comparative artifactual analysis Lacey Point appears engaged in local ceramic exchange networks, but at a disproportionally high scale and variability.

The presence of deliberately themed petroglyphs, grinding slicks, and a cupule slab are features more clearly indicative of a ceremonial site. Lacey Point's conspicuous placement above the surrounding landscape is another telling aspect of its potential ritual function. Shrines in the American Southwest often occupy elevated places, purposefully placed to form line of sight relationships to other shrines and sanctified landmarks. Lacey Point also has a clear viewshed to Pilot Rock to the northwest, where a stone ring shrine occupies one of the summits. However, this shrine lacks the large midden and petroglyph concentration found at Lacey Point. The lack of archaeological surveys conducted within the Painted Desert exacerbates our ability to determine the extent of any potential shrine network.

Looking further afield the Chimney Butte site, located atop a prominent volcanic plug among the Hopi Buttes to the northwest of Petrified Forest, appears cut from the same cloth as Lacey Point in its landscape and artifactual context. Chimney Butte was excavated by the Museum of Northern Arizona in 1966 as part of a larger study of the archaeology of the Little Colorado River basin (Gumerman, 1969:298–305). A single room structure is perched at the summit of Chimney Butte, rising some 1000 feet above the surrounding plain. The walls consist of a single course of basalt cobbles, likely forming the foundation of a jacal structure. A total of 125 sherds were excavated from ritual importance

Chimney Butte, with 85.6% comprising a mixture of Tusayan, Little Colorado, Tseigi, and Hopi painted vessels, and the remaining 14.4% being corrugated gray and brownwares from the Tusayan and Little Colorado regions. These ceramics represent a broad temporal span, dating Chimney Butte to the Pueblo II-IV periods. Cushing (1965:14) reports Zuni consultants identified Chimney Butte as the home of Te-na-tsa-li, or the "Medicine Flower", with Hopi ritual specialists making offerings to this spirit figure at a summit shrine. The inaccessibility of the site, small structure paired with a diverse ceramic assemblage, and continued to the Hopi villages of Second Mesa all point toward Chimney Butte being a ceremonial site.

Lacey Point and Chimney Butte may represent a distinct type of ceremonial site, characterized by elevated placement above the landscape with limited access, the presence of simple jacal structures, and a regionally diverse assemblage of painted ceramics. Lacey Point appears symbolically structured stage for ritual performance, through channeling human movement via a single-entry point into a space dominated by symbolic displays of regional ideological traditions. During pilgrimage journeys, shrines and other ceremonial sites are typically visited in succession, following prescribed paths and carefully choreographed movements (Titiev, 1935; Turner and Turner, 1978; Van Vlack, 2012). With numerous petroglyph sites on the Painted Desert terrace, including the largest concentration of petroglyphs in the park at the nearby Boundary Site, people would have processed through a figured landscape replete with symbolic structures. No petroglyphs are mentioned in association with Chimney Butte, but this is likely due to a lack of suitable rock surfaces surrounding the site (Gumerman, 1969:30). At each site regionally diverse ceramics were used and deposited, with additional evidence of ceramic and flaked stone tool production, food preparation, and gambling present at Lacey Point.

CONCLUSIONS

Moving Toward a More Holistic Appraisal of Rock Images

Landscape iconography, in the form of petroglyphs and pictographs, are often equally enigmatic as they are visually beguiling. The desire to know the meaning behind the image is a driving catalyst for studying rock imagery sites, stretching back as early as 17th century Puritan minister Cotton Mather's attempts to decode the Dighton Rock petroglyphs near Berkley, Massachusetts (Wright, 2014). Chaffing at the ambiguous meaning of non-Western iconographic displays, archaeologists and the public alike attempt to draw out long lost ancient knowledge embodied in rock images. Rogers (2018) observes much of the public language surrounding rock imagery sites, such as the multiple "Newspaper Rocks" found throughout the American Southwest, reflects the desire for traditional indigenous iconography to constitute a form of lost writing, just waiting to be deciphered. Often the quest for finding meaning narrows in on individual images, overemphasizing aesthetic and individual form over more prosaic functions, materials, and placements within the greater archaeological landscape (Tacon and Chippindale, 1998).

Ethnographically informed theories of Lacey Point's petroglyphs enshrining a ritual site become all the more compelling

when backed by other forms of data. A comparative ceramic analysis confirms Lacey Point has a disproportionately large and diverse ceramic assemblage, lending credence to the site hosting regional ceremonial gatherings. The cupule slab and grinding slicks further suggest formalized acts of ritual performance. Examining the landscape context reveals Lacey Point as a visually prominent and physically elevated space with a naturally constricted point of access. The broader archaeological scope of the region reveals ritual structures were constructed in a variety of forms, including the Chimney Butte site which closely resembles Lacey Point in its architecture, ceramics, and topographic location. However, the non-ceramic contents of the midden suggest a range of both ritualized and domestic activities took place around the summit of Lacey Point. The complexity of Lacey Point's artifacts and features demonstrates the limitations of fitting nuanced variability into preconceived site typologies.

Historically, indigenous pilgrimages in the American Southwest were typically undertaken by select ritual specialists from the community (Fowles, 2009; Van Vlack, 2012; Wright, 1988). Routine visitation of such groups from different villages may account for the intensive and diverse refuse assemblage at Lacey Point, with perhaps site caretakers accounting for some of the more characteristically domestic contents of the midden. There are multiple lines for future research at Lacey Point. A zooarchaeological analysis of the site's faunal remains may better inform us of the types of animals consumed and how they were prepared. Collaboration and consultation with descendant communities gives the opportunity for reconnecting individuals with an ancestral cultural space and potentially yield insights into the significance and purpose of Lacey Point. Finally, more comprehensive surveys are required of the Painted Desert to create a more holistic understanding of the cultural landscape Lacey Point was enmeshed in.

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APPENDIX

TABLE 1. Characteristics of four sampled Painted Desert sites

Lacey Point/PEFO00574:

- Small field house-sized structure.
- Located on an isolated landform within the Painted Desert.
- Reported to contain large and diverse ceramic assemblage.

PEFO00551:

- Small field house-sized structure.
- Located on mesa rim above Painted Desert.
- Suspected to containt a small and uniform ceramic assemblage.

PEFO 00608:

- Large pueblo roomblocks.
- Located on mesa rim above Painted Desert.
- Suspected to containt a large and diverse ceramic assemblage.

PEFO 00575:

- Large pueblo roomblocks.
- Located on an isolated landform within the Painted Desert.
- Suspected to containt a large and diverse ceramic assemblage.

TABLE 2. Tally of grayware and brownware types.

	Puerco Valley grayware	Little Colorado grayware	Cibola grayware	Tusayan grayware	Unknown grayware	Puerco Valley brownware	Woodruff brown	Show Low smudged
PEFO00574	396	21	3	10	1	2	34	5
PEFO00551	14	11	2	2	0	0	1	0
PEFO00575	30	3	0	1	0	0	0	1
PEFO00608	121	12	0	1	0	1	8	3

TABLE 3. Tally of redware, polychrome, and yellowware types.

	Puerco Valley redware	Show Low red	Show Low red corrugated	Show Low black-on-red	Homolovi black-on-red	Heshi black-on-red	St. Johns black-on-red
PEFO00574	0	4	1	7	1	1	1
PEFO00551	0	0	0	0	0	0	0
PEFO00575	0	3	1	0	0	0	0
PEFO00608	1	3	1	10	0	0	0

APPENDIX *(continued)*

TABLE 3 *(continued)*. Tally of redware, polychrome, and yellowware types.

	Puerco Valley black-on-red	Wingate black-on-red	Indeterminate White Mountain black-on-reds	St. Johns polychrome	Wingate polychrome	Indeterminate White Mountain redware polychromes	Tsegi orange
PEFO00574	8	6	22	4	3	4	1
PEFO00551	1	0	3	0	0	0	0
PEFO00575	0	0	0	0	0	0	0
PEFO00608	3	1	13	2	0	2	0

TABLE 3 *(continued)*. Tally of redware, polychrome, and yellowware types.

	Tsegi red-on-orange	Winslow orange	Awatovi black-on-yellow	Jeddito yellow	Indeterminate redwares
PEFO00574	1	0	1	3	7
PEFO00551	0	0	0	0	0
PEFO00575	0	0	0	0	0
PEFO00608	0	1	0	0	0

TABLE 4. Tally of whiteware types.

	Lino black-on-white	Leupp black-on-white	Puerco black-on-white	Padre black-on-white	Klagetoh black-on-white	Walnut black-on-white
PEFO00574	2	3	2	3	2	2
PEFO00551	0	0	0	1	0	0
PEFO00575	0	0	0	0	0	1
PEFO00608	0	1	0	1	0	6

TABLE 4 *(continued)*. Tally of whiteware types.

	Flagstaff black-on-white	Snowflake black-on-white	Dogoszhi black-on-white	Holbrook black-on-white	Reserve black-on-white	Escavada black-on-white
PEFO00574	0	3	4	3	2	3
PEFO00551	0	1	0	2	0	0
PEFO00575	0	0	0	2	0	0
PEFO00608	1	0	1	0	0	0

APPENDIX *(continued)*

TABLE 4 *(continued)*. Tally of whiteware types.

	Red Mesa black-on-white	Tularosa black-on-white	Pinnawa glazed black-on-white	Indeterminate Zuni glazed black-on-white	Indeterminate Little Colorado whiteware	Cibola whiteware indeterminate	Tusayan whiteware indetermimate
PEFO00574	1	1	1	0	30	18	22
PEFO00551	0	1	0	0	1	3	0
PEFO00575	0	0	0	0	5	2	0
PEFO00608	1	5	0	1	14	4	4

TABLE 5. Average sherds per square meter.

	Average
PEFO00574	11.8
PEFO00551	2.41
PEFO00575	1.16
PEFO00608	4.42

TABLE 6. Percentage of ceramic wares.

	Greywares	Brownwares	Whitewares	Redwares	Polychromes	Yellowwares	Indeterminate
PEFO00574	66.21%	6.29%	15.52%	9.52%	1.69%	0.61%	0.15%
PEFO00551	70.73%	2.44%	17.07%	9.75%	0.00%	0.00%	0.00%
PEFO00575	65.38%	1.92%	19.23%	13.45%	0.00%	0.00%	0.00%
PEFO00608	60.93%	5.43%	17.65%	14.00%	1.81%	0.00%	0.00%

TABLE 7. Ceramic types represented per site.

	Whitewares	Redwares	Polychromes	Greywares	Brownwares	Yellowwares	Total types
PEFO00574	14	10	3	4	3	2	36
PEFO00551	3	1	0	4	1	0	9
PEFO00575	2	4	0	3	1	0	10
PEFO00608	7	6	1	3	3	0	20

APPENDIX *(continued)*

TABLE 8. Percentage of ceramic vessel forms.

	Jar	Bowl	Ladle	Shaped	Indeterminate
PEFO00574	73.73%	21.20%	0.92%	0.61%	3.38%
PEFO00551	87.80%	9.76%	0%	0%	2.42%
PEFO00575	76.92%	19.23%	1.92%	1.92%	0%
PEFO00608	70.14%	28.05%	1.36%	0%	0.45%

TABLE 8. Percentage of ceramic vessel forms.

	Jar	Bowl	Ladle	Shaped	Indeterminate
PEFO00574	73.73%	21.20%	0.92%	0.61%	3.38%
PEFO00551	87.80%	9.76%	0%	0%	2.42%
PEFO00575	76.92%	19.23%	1.92%	1.92%	0%
PEFO00608	70.14%	28.05%	1.36%	0%	0.45%

TABLE 4. Percentage of regional whiteware traditions.

	Little Colorado	Tusayan	Cibola	Zuni
PEFO00574	40.59%	27.72%	30.69%	0.99%
PEFO00551	28.57%	0%	71.42%	0%
PEFO00575	90%	0%	10%	0%
PEFO00608	56.41%	15.39%	25.64%	2.56%

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RESILIENCE OF THE GLADIATOR MILKVETCH (*ASTRAGALUS XIPHOIDES*), A RARE, ENDEMIC PLANT OF PETRIFIED FOREST NATIONAL PARK, OVER A CENTURY AND THROUGH PROLONGED DROUGHT

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ABSTRACT — Hiding among eroding badlands, hoodoos, and ephemeral washes of Petrified Forest National Park is a rare, narrow endemic with a peculiar name, the Gladiator milkvetch (*Astragalus xiphoides*). First discovered in the park in 1940, its scarcity and range were largely unknown until the 1980s when the species was designated as a candidate for listing under the Endangered Species Act. Focused surveys for the species were conducted in Petrified Forest National Park in 1989, identifying 16 distinct populations. Beginning in 1995, the park experienced a 27-year period of prolonged drought ending in 2022. This article summarizes the recent efforts by the National Park Service to locate these 16 populations in order to assess the plants resilience through prolonged drought. Eight of the populations surveyed in 1989 persist today, with some populations declining in density by 80–90 percent and others remaining stable with modest increases in density.

Keywords: *Astragalus xiphoides*, Gladiator milkvetch, Petrified Forest National Park, drought, endemic, Colorado Plateau.

INTRODUCTION

First collected over a century ago in 1922 by Cornell University botanists Karl Wiegand and George Upton, Gladiator milkvetch (*Astragalus xiphoides*) remains a poorly understood narrow endemic of Petrified Forest National Park (PEFO) and surrounding areas of northeast Arizona. The plant's distribution is consistent with it being a substrate endemic associated with soils derived from the Sonsela Member of the Chinle Formation, the underlying geologic formation of PEFO. This rare plant can be locally abundant but has a patchy distribution and is not found in all potential habitat. Gladiator milkvetch was first discovered in PEFO in 1940 by National Park Service (NPS) Naturalist Carl Jepson. Since that discovery, no inquiries or surveys of the species were performed in PEFO until surveys for the plant were conducted by the NPS in 1989 (Knight 1989). There are insufficient data to definitively determine the long-term trends of this species in PEFO. Unfortunately, until this study, the numbers of individual plants were often not counted or even estimated when populations were found. In the 1980s, as more areas within PEFO were searched and NPS personnel become more familiar with the species, the numbers of documented occurrences increased (Phillips et al. 1982; Knight 1989).

Gladiator milkvetch was a candidate for listing under the Endangered Species Act (ESA) in the 1980s and 1990s and is listed as a state species of concern due to

to its rarity and restricted geographic range. Current information on this species is needed to better understand its status and extent within PEFO to properly manage for its continued persistence. Prolonged drought, park maintenance (roadside mowing), spread of exotic plants, herbivory, and visitor impacts are factors that can affect Gladiator milkvetch and its habitat. Little is known about the response of this species to these impacts, which creates a challenging situation for the NPS to develop strategies to ensure the health of this species and to avoid or mitigate potential impacts to it.

Gladiator milkvetch has a global conservation status ranking of G3 (Vulnerable), a state ranking of S3 (Vulnerable), and a Navajo Nation ranking of S2 (Sensitive Species) (NatureServe 2022). This species contributes to the uniqueness and diversity of flora within PEFO and the greater Colorado Plateau. Despite having most of its known habitat protected within a national park, little has been done to document its existence or develop NPS management strategies, if needed, to ensure its continued persistence. This study documents the current range and density of Gladiator milkvetch populations within PEFO. Most of the populations included in this study were first discovered and surveyed in the 1980s. Further informa-tion on the plant's phenology, range, pop-ulation size, population dynamics, and genetics may assist federal agencies in determining whether future protections or conservation of critical habitat is appropriate. Critical habitat for this species has not been defined and limited measures are in place to protect this species.

The last survey of Gladiator milkvetch in PEFO occurred 34 years ago (Knight 1989). Findings from that survey are useful but inconsistent, ranging from intensive survey at certain locations to incidental observations without estimates of plant density or geographic extent at other locations. The 1989 survey included hand-drawn range maps for each population surveyed but locations were imprecise, and the level of survey varied by population. Two herbarium vouchers from the 1990s were also found to be incorrectly identified as Gladiator milkvetch. For these reasons, NPS initiated this study and began conducting a new survey of the species in 2022. Locations from the 1989 survey, herbarium vouchers from SEINet and PEFO collections (SEINet 2022), observations from iNaturalist (iNaturalist, 2023), and a review of GIS layers (vegetation mapping, geology, soil types, and aerial photography) provided the basis for new survey. Apart from these resources, historic accounts of Gladiator milkvetch in PEFO are sporadic, incomplete, and perhaps inaccurate due to taxonomic confusion with similar looking *Astragalus*.

Starting in 1995, PEFO experienced a period of prolonged drought that lasted for nearly 27 years (Fig. 1). Drought conditions began in 1995 with most years being abnormally dry, occasionally interrupted by a wet year or two (Arizona State Climate Office (ASCO) 2023). In early 2022, PEFO was still suffering 'Extreme' and 'Severe' conditions of long-term drought; notably the poorest drought conditions assigned by the ASCO. By the end of 2022, PEFO had experienced a wetter than normal year and showed signs of recovery from long-term drought (ASCO 2023, Fig. 1). Consequently, the 2022 growing season may also represent one of the most productive seasons in PEFO for plant growth, diversity, and richness in decades. A comparison of plant counts from the 1989 survey (pre-drought) to the 2023 survey (post-drought) gives NPS a measure of the

resilience of Gladiator milkvetch to prolonged drought and some indication of recovery from it.

Further study beyond presence-absence surveys is needed to fully document the resilience of Gladiator milkvetch populations over time. Factors such as edaphic stress, genetic isolation and gene flow, climate change, herbivory, and hyperaccumulation of selenium and other minerals from badland soils may also influence the endemism and survival of this species in PEFO. Without overlooking the importance of these factors, NPS's primary need and near singular purpose of this study was to answer the basic question of "how many plants, and where?" This study summarizes our approach and findings for answering that basic question and provides an analysis of how prolonged drought may influence the long-term survival of Gladiator milkvetch in PEFO.

BACKGROUND

Gladiator milkvetch is a plant within the *Astragalus* genera of the Fabaceae family. *Astragalus* is a genus of vascular plants with considerable species richness, comprising over 3,000 species widely distributed across the Northern Hemisphere and South America. Many *Astragalus* species, much like Gladiator milkvetch, occupy small, patchy distributions with narrow habitat requirements which may promote genetic isolation and increased speciation (Massatti et al., 2018). Due to their restricted and patchy distribution, many species of *Astragalus* are often of conservation concern.

The geographic range of Gladiator milkvetch is limited to specific areas in the Little Colorado River watershed, including PEFO and scattered areas on Navajo Nation tribal lands. The plant is endemic to this range and occurs nowhere else in the world. Gladiator milkvetch was designated by U.S. Fish and Wildlife Service (USFWS) as a Category 1[1] candidate species for listing under the ESA in 1980, 1985, and 1990 (USFWS 2022). The species was downgraded to a Category 2[2] candidate species in 1993 (USFWS 1993). In 1996, USFWS discontinued the use of Category 2 as a species designation and there are no current plans to list the plant (USFWS 1996). The species is protected as a salvage restricted species under the Arizona Native Plant Law (A.R.S. §§ 3-341 et seq. and 3-3101 et seq; Arizona Department of Agriculture 2022) which is administered by the Arizona Department of Agriculture. The Arizona Native Plant Law was enacted to protect rare plant species and to protect some species from being over-harvested.

Specific information on population dynamics, genetics, and life stages of Gladiator milkvetch is mostly unknown. The plant was first discovered and collected approximately 12 miles east of Holbrook, Arizona in 1922 during a botanical expedition led by Cornell University. The plant was first grouped taxonomically with *A. junceus*, an *Astragalus* known from central Utah and Colorado. In 1940, NPS Naturalist Carl Jepsen collected a specimen of the plant near Crystal Forest

[1]Category 1 - Taxa for which the USFWS has on file sufficient information on biological vulnerability and threat(s) to support proposals to list them as endangered or threatened species (USFWS 1993).

[2]Category 2 - Taxa for which information now in the possession of the USFWS indicates that proposing to list as endangered or threatened is possibly appropriate, but for which sufficient data on biological vulnerability and threat are not currently available to support proposed rules (USFWS 1993).

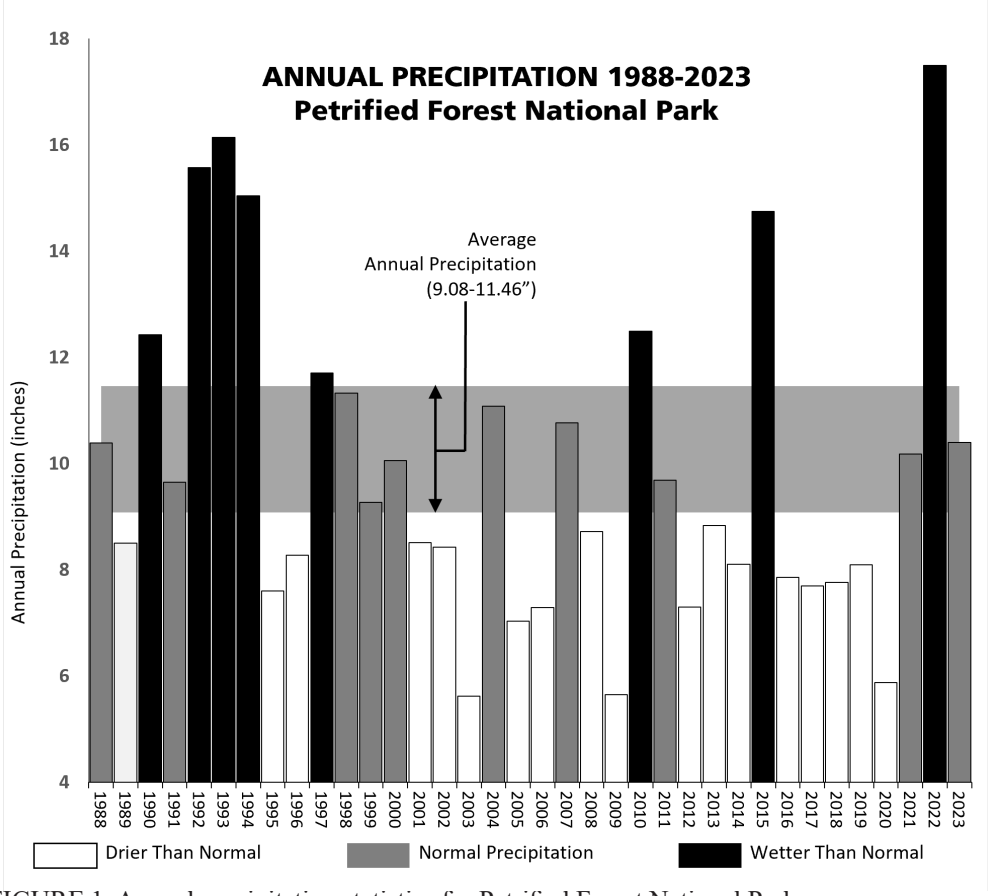


FIGURE 1. Annual precipitation statistics for Petrified Forest National Park.

in PEFO. Jepsen prepared an herbarium voucher and identified the plant as *A. junciformus*, an early name for what taxonomically became *A. convallarius*. The plant was first described botanically and treated as a subspecies (var. *xiphoides)* of *A. convallarius* in 1947 (Barneby 1947). Gladiator milkvetch was later separated taxonomically and treated as a distinct species in 1964 as *A. xiphoides*, an endemic to northeastern Arizona and PEFO (Barneby 1964). No scientific literature or detailed species accounts are available for this species. Table 1 provides a timeline that highlights the discovery, taxonomic changes, various treatments, and surveys of this species over the past century.

SPECIES OVERVIEW

Gladiator milkvetch is an herbaceous perennial forb. The plant has a broom-like appearance, with rigid stems rising from the ground level branching and the larger branches branching again (Fig. 2). The plants stems are strigulose-cinereous, green in color throughout with fine straight hairs up to 0.5 mm long covering the entire plant. The lowest stems are a purplish-red color from the ground level to the first node where branching begins or even slightly above the node. Older, mature plants, as an average grow 30–45 cm tall, some with more vigorous growth being up to 1 m tall. Any leaves present are linear in form from

TABLE 1. Historical timeline of discovery, treatment, and survey of the Gladiator milkvetch .

Year	Event
1922	First collected and identified as *A. junceus* - 12 miles east of Holbrook, AZ by M.C. Wiegand and G.B. Upton. New York Botanical Garden Steere Herbarium Catalog No. 01344301.
1940	First collected in PEFO and identified as *A. junciformus* - 0.5 miles west of First Forest by Carl Jepson. Petrified Forest National Park Herbarium Catalog No. 1698.
1947	First botanical treatment as *A. convallarius* var. xiphoides - R.C. Barneby in the publication “Leaflets of Western Botany Volume 5” (Barneby 1947)
1964	First botanical treatment as *A. xiphoidies* - R.C. Barneby in the publication "Atlas of North American *Astragalus*" (Barneby 1964).
1980	USFWS lists A. xiphoides as a Category 1 Candidate Species for protection under the ESA.
1982	Focused surveys of *A. xiphoidies* across northeastern Arizona in support of USFWS Candidate Species designation – completed by Arthur and Barbara Phillips (Phillips et al., 1982).
1985	USFWS maintains *A. xiphoidies* as a Category 1 Candidate Species for protection under the ESA.
1989	Focused surveys of *A. xiphoidies* in PEFO – completed by Ferral Knight (Knight 1989).
1990	USFWS maintains *A. xiphoidies* as a Category 1 Candidate Species for protection under the ESA.
1993	USFWS downgrades *A. xiphoidies* to a Category 2 Candidate Species for protection under the ESA (USFWS 1993).
1996	USFWS discontinues the use of Category 2 as a species designation and *A. xiphoidies* is removed from consideration for listing under the ESA.
2001	*A. xiphoidies* Suitable Habitat Study – completed by Sue Clements (NPS).
2022/2023	Focused surveys of *A. xiphoidies* in PEFO – completed by Jeff Schively and Dan Carroll (NPS).

2.5–13 cm long and indistinguishable from the stems (Barneby 1964; Knight 1989).

The plant typically flowers from April to June but has also been observed flowering later in fall during active monsoon seasons (Arizona Rare Plant Committee 2001). Gladiator milkvetch can produce many small, pale, yellow flowers extending from near or well below he middle of the plant upward. The flowers range from 2–7 mm long and are rather inconspicuous due to both color and small size (Fig. 2). The petals are strongly incurved and have a purplish rib extending laterally through the center of the top and bottom petals. The flat, two-edged seed pods are 25–40 mm long and 4–6 mm wide , pale green in color but have a reddish-pink tint over all or part of the

seedpod. The plant's seedpods hang pendulously from the upper stems, looking much like a gladiator's sword, hence the common name Gladiator milkvetch (Knight 1989). A small, 1 mm or less, hook is found on the end of the pod. Seedpods tend to persist on the plant through at least November. Mature seeds are a dull brown in color (Barneby 1964; Knight 1989). Figure 2 illustrates characteristics of the plant's flowers and seedpods.

The patchy nature of its spatial distribution suggests seed dispersal may often be limited and localized around the parent plant. There is no evidence of hybridization between Gladiator milkvetch with other *Astragalus* species in PEFO. Only one other *Astragalus* was documented as sympatric, wooly locoweed (*A. mollissimus*), the most widespread milkvetch in PEFO and not closely related or visually similar to Gladiator milkvetch. No intermediates between the two have been observed. Bishop's milkvetch, *A. episcopus* var. *episcopus*, is another rare filiform *Astragalus* in PEFO that has been confused with Gladiator milkvetch in past surveys. The species, found only at two isolated locations in PEFO, is closely related to Gladiator milkvetch but is not sympatric. One other milkvetch, a filiform variety of painted milkvetch (*A. ceramicus* var. *filifolius*), is another uncommon milkvetch in PEFO that can easily be confused with Gladiator milkvetch when plants lack flowers or seedpods. Painted milkvetch has not been observed as sympatric with Gladiator milkvetch in PEFO.

Seedlings and smaller, nonflowering plants generally have only a single, pliable stem at the base of each plant. Larger, mature plants typically have multiple, rigid stems at the base of each plant. Larger plants also retain previous year's growth at the base of the plant, a trait that is helpful in field identification when flowers or seedpods are absent. A review of herbarium vouchers show that rhizomes of larger, mature plants are thick (4–12 mm) and woody. In comparison, rhizomes of seedlings and smaller, nonflowering plants are much thinner (2–5 mm), lack a woody appearance, and are less developed. More information is needed to fully understand the average depth and reach of the plants roots relative to plant age and reproductive status. It is assumed that larger, mature plants have both deeper and wider spreading roots that allow the plant to capture precipitation and soil moisture more efficiently during dry climatic conditions. This trait would be more advantageous for plants trying to survive prolonged drought (Noy-Meir 1973).

METHODS

Historical accounts and documentation of Gladiator milkvetch are quite limited. Most information gathered for this study came from archived reports, maps, and data stored by the Museum of Northern Arizona in Flagstaff, Arizona. Additional information on past sightings were discovered in archived files and reports at PEFO. Other than the information from those two sources, the species has received little attention from the scientific community or associated regional plant studies. The species is meticulously described in several plant identification books for taxonomic purposes, but little information is given on the plants geographic range or population size. In reviewing information assembled for this study, it's clear that even less is known about the life history, population ecology, or demographics of this species. Most information available for the species is

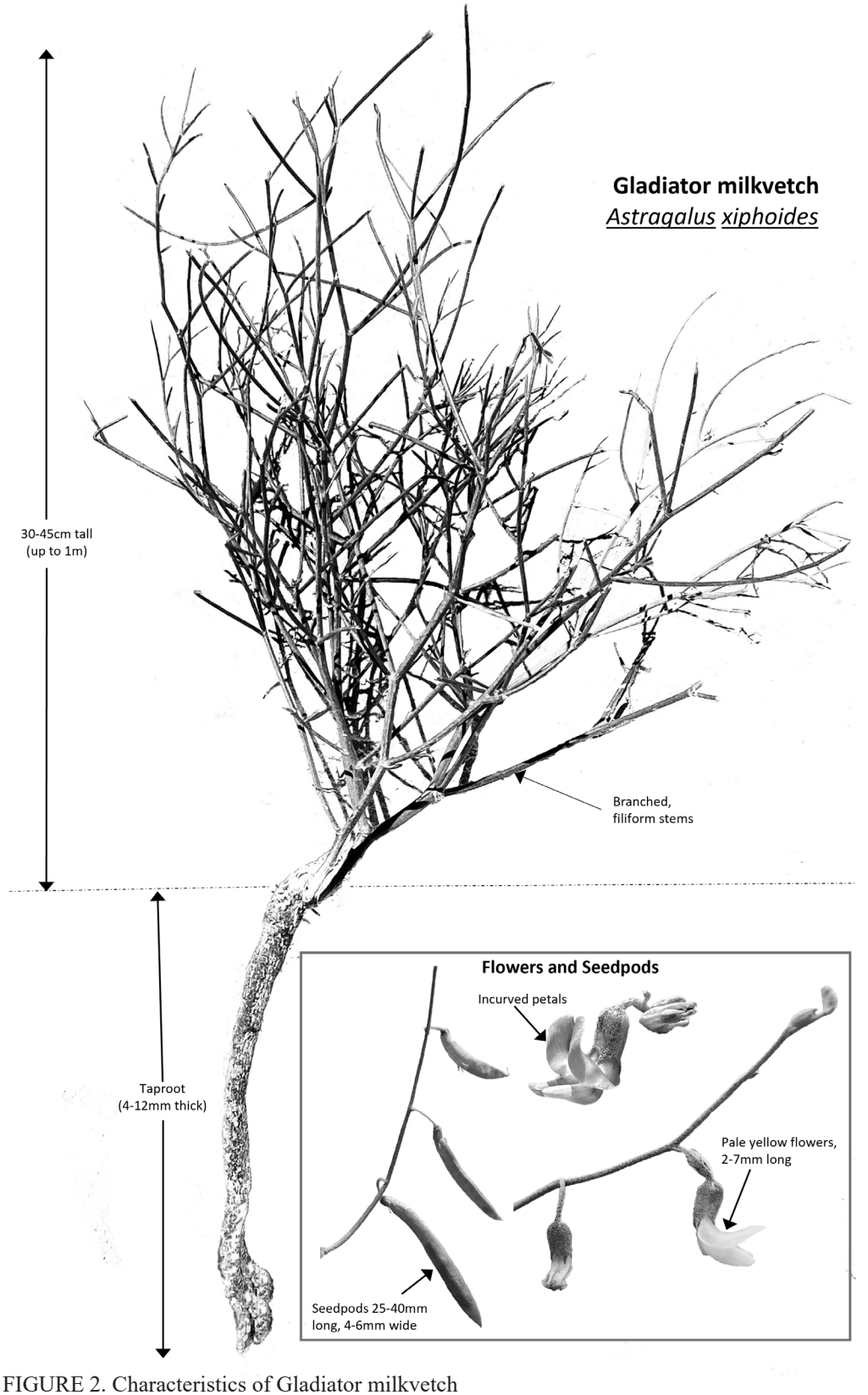


FIGURE 2. Characteristics of Gladiator milkvetch

related to documentation of its presence at discreet locations within PEFO and surrounding areas.

Two resources, the 1989 survey (Knight) and the 1982 survey (Phillips et al.), proved to be most useful for this study. Each documented distinct populations of Gladiator milkvetch in and around PEFO and provided observations on various botanical and ecological traits of the plant. Information from these surveys provided the basis for locating populations in PEFO reviewed for this study. Hand-drawn polygons on photocopied U.S. Geological Survey topographic maps were included in each survey report. These maps were digitized onto orthorectified aerial photography in a GIS database and used in conjunction with a handheld GPS unit to navigate to each location. Areas within and around each digitized area were surveyed for Gladiator milkvetch in 2022 and 2023. Additional areas with similar soil types across similar landforms where the plant had previously been documented were added to the search area through a review of GIS layers (soil mapping, geology, topography, and vegetation mapping) and aerial photography.

A total of 16 distinct populations were identified from past surveys in PEFO. Locations noted on herbarium vouchers cataloged at the Northern Arizona University (NAU) Deaver Herbarium and the PEFO Herbarium Collection were also cross-referenced to the known populations to ensure that the plants were correctly identified as Gladiator milkvetch. Anecdotal accounts, such as iNaturalist submissions (iNaturalist 2023) and brief mentions of the plant in PEFO Management Plan publications were also reviewed and cross-referenced to previously surveyed populations. For this study, each population was resurveyed to help determine whether the populations persisted through prolonged drought, if the number of individual plants changed, and whether the geographic reach of each population had changed. Information from this survey is intended to provide the basis for developing future NPS strategies for monitoring and protection of this species in the park.

Focused rare plant surveys for Gladiator milkvetch were conducted in 2022 and 2023 across known and suspected habitats in PEFO. Surveys were conducted utilizing an intuitive control search method to focus on soil types and microhabitats most suitable to support the plant. When plants were encountered, a complete 100 percent survey method was used to locate and GPS individual plants within distinct populations. Surveys followed existing protocols for plant survey as defined by Whiteaker et. al 1998

Suitable terrain within and adjacent to each known population was surveyed on foot to determine the extent and number of plants within each population. Observations regarding the size and maturity of plants and their flowering stage were also noted when flowers or seed pods were observed. Upon returning from the field, the extent of each population was delineated in GIS using GPS locations, field notes, site photographs, and orthorectified aerial photography.

RESULTS

The 16 populations previously known in PEFO are shown on Figure 3 and listed in Table 2. Populations depicted on Figure 3 as black circled numbers indicate populations still present today. Populations depicted as gray circled numbers on Figure 3 are either extirpated, not Gladiator milkvetch (two previously

surveyed populations were found to be a different *Astragalus*) or require additional survey to confirm their status. Substantial effort was made to locate each known population for this study. Exact locations and estimates of population size from the 1982 and 1989 surveys were not available for all locations. A detailed account of the number of individual plants at each population was performed for this study. In most cases, individual plants were marked in the field using handheld GPS unit and that data imported into a GIS database. Many other locations within the park with similar habitat features were surveyed for the milkvetch but did not support the plant.

Population trends are particularly difficult to predict for this species from the limited observations made over relatively short periods of time with a 34-year lapse between surveys. Evidence from this study suggests that numbers of plants at any given population can vary considerably over time. For example, several small populations have become extirpated, several have decreased in density by as much as 80–90 percent, while other populations are believed to have increased in density since 1989 (Table 2). Regardless of population trends, each population surveyed for this study are small, isolated occurrences with relatively few individuals when compared to other, more common plants in PEFO.

Underlying soils at all milkvetch populations have similar characteristics in color and texture, all having light tan colored, sandy upland soils. USFWS describes the soil requirements for Gladiator milkvetch to be in drainages or on lenses of gypsum or gypsiferous sand near the dissected hills of the Chinle Formation. This gypsum is exposed in several small areas from near Holbrook and east to PEFO (USFWS 1990). Further investigations are needed to fully understand the specific ranges of soil type, chemistry, and composition that support the plant.

Of the 16 distinct populations of Gladiator milkvetch known to occur in PEFO in the 1980s, 8 still exist today (Table 2). The number associated with each population on Figure 3 and Table 2 is listed after the named locations in the narrative below. The surviving populations include Agate Bridge (2), Blue Mesa (3), Chinde Mesa (4), Chinde Wash (6), Zuni Well Sandbar (10), Lithodendron Wash (12), Devil's Playground Jeep Trail (14), and Cedar Tank (15). Four of these locations (2, 3, 4, and 10) have experienced considerable loss in plant numbers, estimated at 80–90% fewer plants, since 1989. The remaining four locations (6, 12, 14, and 15) show signs of being relatively stable populations and have either maintained or increased in plant number since 1989.

Six populations were not found in this survey. Three of these, Crystal Forest (1), Zuni Well East (11), and Blue Mesa Turnoff (13), are believed to be extirpated and no longer exist. Each of these populations were originally documented as having only a few plants and surveyors could not find any evidence to support that milkvetch had survived at these locations. The remaining three populations, Black Forest (5) and Lithodendron Wash Northwest and Southwest (8 and 9), were not found in 2023 but additional survey is planned to confirm their status. The 1989 survey describes these three populations as having large numbers of scattered Gladiator milkvetch across widespread areas along the Lithodendron Wash floodplain and adjoining badland areas. Not all areas within and around these previously documented populations were surveyed. Portions of each

were surveyed in 2023 but no Gladiator milkvetch was found. The remaining portions not surveyed are anticipated to be surveyed in 2024.

Two populations previously thought to be Gladiator milkvetch, including the Kokopelli Tinaja (7) and Borrow Pit (16) populations, were discovered to be populations of a different species of *Astragalus*. With assistance from NAU Deaver Herbarium staff, two herbarium vouchers from 1991 and 1993 collected at the Borrow Pit (16) population, were revisited, and determined to be specimens of Bishop's milkvetch, *A. episcopus* var. *episcopus*. Additional plant diagnostic features on live plants were sought at each site in 2023 and it was confirmed that these two locations did not contain Gladiator milkvetch, and instead Bishop's milkvetch. Both are visibly similar in appearance with slight differences in flower color and other minor botanical features. These two populations will be

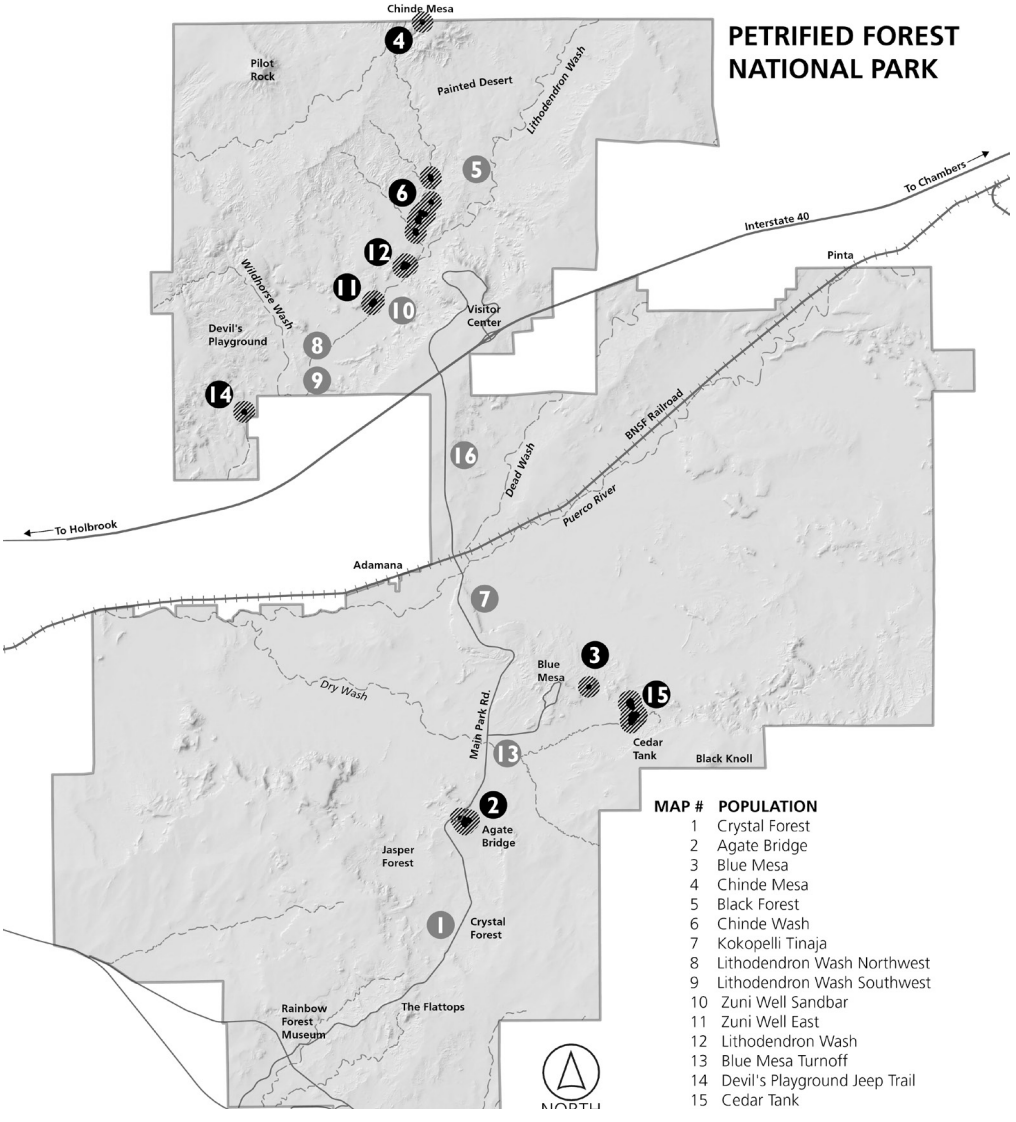


FIGURE 3. 2023 populations of Gladiator milkvetch in Petrified Forest National Park

TABLE 2. Known populations of Gladiator milkvetch in Petrified Forest National Park, Arizona.

Map Number	Location	Year Discovered	# of Plants (1980s Survey)	# of Plants (2022/2023 Surveys)	Notes on Population
1	Crystal Forest	1940 (Bowman)	0	0	Population likely extirpated
2	Agate Bridge	1980 (Kierstead)	2,776	554	Estimated population decrease of 80%
3	Blue Mesa	1988 (Hysell)	448	45	Estimated population decrease of 90%
4	Chinde Mesa	1988 Hysell)	236	5	Estimated population decrease of 90+%
5	Black Forest	1988 (Knight)	No count	Unknown	Additional survey needed; not located in 2023
6	Chinde Wash	1988 (Knight, Hysell, Heward)	No count; estimated in the thousands	755	Estimated population decrease of 60–80%
7	Kokopelli Tinaja	1989 (Knight)	No count	None	Misidentified as *A. xiphoides*; population of Bishop's milkvetch (*A. episcopus* var. *episcopus*)
8	Lithodendron Wash Northwest	1989 (Knight)	No count	Unknown	Additional survey needed; not located in 2023
9	Lithodendron Wash Southwest	1989 (Knight)	No count	Unknown	Additional survey needed; not located in 2023
10	Zuni Well Sandbar	1989 (Knight)	No count; estimated <50 plants	9	Estimated population decrease of 80–90%
11	Zuni Well East	1989 (Knight)	No count; estimated <50 plants	0	Population likely extirpated
12	Lithodendron Wash	1989 (Knight)	No count	283	No population estimate from 1989 to compare to; likely a stable population

TABLE 2 (*continued*). Known populations of Gladiator milkvetch in Petrified Forest National Park, Arizona.

Map Number	Location	Year Discovered	# of Plants (1980s Survey)	# of Plants (2022/2023 Surveys)	Notes on Population
13	Blue Mesa Turnoff	1989 (Gori, Knight)	25	0	Population likely extirpated
14	Devil's Playground Jeep Trail	1982 (Phillips)	60	118	Stable population. Estimated population increase by nearly 200%
15	Cedar Tank	1982 (Rutman)	No count	1,405	No population estimate from 1980s to compare to; likely a stable population
16	Borrow Pit	1991 (Knight)	No count	None	Misidentified as *A. xiphoides*; population of Bishop's milkvetch (*A. episcopus* var. *episcopus*) and Painted milkvetch (*A. ceramicus* var. *filifolius*)

removed from the list of known Gladiator milkvetch populations in PEFO. Bishop's milkvetch is also considered an *Astragalus* of conservation concern and the NPS may elect to manage it as a rare plant in PEFO.

The total number of individual Gladiator milkvetch plants in PEFO is estimated to be 3,000–4,000. This accounts for 3,174 individual plants counted during surveys completed for this study and another estimated 500–800 plants at the three populations (5, 8, and 9) documented in 1989 that require additional survey to confirm their status. Portions of those three populations were surveyed in 2023 and no milkvetch was found.

DISCUSSION

Nearly one third of all plant species are classified as 'rare' and many of them grow in areas where the climate has been very stable for a long time (Enquist et al., 2019), indicating that many rare plants might be poorly adapted to withstand the effects of prolonged drought. In this study, we investigated the effects of a nearly 30-year drought on populations of Gladiator milkvetch in PEFO. This sparsely distributed, narrow endemic is naturally rare across PEFO even when climatic conditions are favorable. Climate extremes such as severe drought can have widespread and long-lasting impacts on the vegetation composition of landscapes (Hanson and Weltzin 2000). Long-term drought can further exacer-

bate stresses on plants which can lead to reduced plant productivity, reproduction rates and seedling survival, and often plant mortality (Lindell et al. 2022).

Following 27 years of prolonged drought, Gladiator milkvetch still maintains its presence across the weathered badlands of PEFO. This rare endemic shows signs of resilience and resistance to drought but has also experienced considerable losses over that same time. Water availability is projected to decrease over the next century due to reduced precipitation and increased temperatures (Seager et al., 2007). Extreme droughts are projected to increase in frequency, duration, and severity across the Southwest, with droughts potentially more likely in the cool season (Cook et al., 2014; Seager et al., 2007). Low rates of recovery from past droughts may reduce a plants resistance to future droughts, as reduced growth or mortality of individuals impact the starting baseline of the new period of drought (Hoover et al., 2021). Documenting the extirpation of three populations of Gladiator milkvetch and a loss of most plants (estimated at 80–90% fewer plants) at another three populations in PEFO could signify an unfavorable trend with the plants long-term survival if drought frequency and severity increases into the future, as predicted.

Rare endemic plants with a low dispersal ability, like the Gladiator milkvetch, often depend on microclimatic refugia and are likely to be particularly vulnerable to changes in temperature and precipitation associated with drought (Enquist et al., 2019). At the same time, it may take considerable time before changes in climate are evident as reductions in the population sizes of long-lived plants (Lindell et al., 2022).

In addition to drought, many other environmental factors may play a role in the long-term survival of the species. Gladiator milkvetch is a narrow endemic restricted to soils derived from the Sonsela Member of the Chinle Formation in PEFO. Narrow endemics, characterized by small distribution areas and small effective population sizes, are prone to extinction due to low genetic variation caused by genetic bottlenecks and drift (Bagheri et al., 2020). Given its limited range and sparse distribution, populations are considered vulnerable, and the survival of this species may be dependent on unknown factors such as the longevity of the plant's taproot, the frequency of seedling recruitment, and seed dispersal. The patchy nature of its spatial distribution suggests seedling recruitment is infrequent and seeds have a restricted dispersal pattern localized around the parent plant. Plants situated near ephemeral washes may benefit from seed dispersal through seasonal flow events, but further study is needed to confirm that assumption. These limitations of dispersal could isolate populations and inhibit gene flow between populations. In smaller populations with only few individual plants, genetic isolation may already be a contributing factor to the decreasing population trends documented in this study.

Loss and alteration of habitat due to erosion was also documented in this study. Seven populations (5, 6, 8, 9, 10, 11, and 12) identified from the 1989 survey occur within active floodplains of the Lithodendron, Wildhorse, and Chinde washes, all being large ephemeral washes in the northern portion of PEFO. These populations are subject to periodic floods, sediment scour and deposition events, and erosional forces which could threaten the survival of each population. Four of these populations (5, 8, 9 and 11), were either determined to be extirpated or not found in 2023, suggesting

that populations located in severe erosional areas may not persist long-term.

Population trends of Gladiator milkvetch in PEFO are difficult to define due to the limited research that this species has received since its initial discovery in 1922. By using this limited data, the variability in survey protocols and confusion in identifying the species in the field presents difficulties in assessing change in populations over time. Conclusions can be made at several populations where full surveys were conducted in 1989 and detailed plant counts are available. At some locations, plant density has decreased considerably between 1989 and 2023. At other locations, plant density has remained stable over this period or has even increased. In either situation, the plant remains a rarely encountered plant in PEFO as it has since its initial detection in the park in 1940.

The persistence of Gladiator milkvetch in PEFO may also signify a positive trend in the resilience of narrow endemics through prolonged drought and climate change. Although current data cannot determine how its abundance and range has been affected over the last century, with the current understanding of its ecology and biology on which to build, it may be an important species for the NPS to monitor in the future. If the NPS decides to monitor this species, a protocol should be developed to increase the frequency of monitoring and avoid prolonged lapses in survey. The survival of Gladiator milkvetch in PEFO provides a compelling example of how a narrow endemic, restricted to only a few isolated populations, demonstrates resilience through a nearly 30-year drought and may, more importantly, suggest that the species could endure some effects of climate change.

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THE ALLOKOTOSAUR (REPTILIA: ARCHOSAUROMORPHA) ASSEMBLAGE FROM A MULTITAXIC BONEBED IN THE SONSELA MEMBER (JIM CAMP WASH BEDS, CHINLE FORMATION) AT PETRIFIED FOREST NATIONAL PARK, U.S.A.

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ABSTRACT — Allokotosaurian archosauromorphs (i.e., trilophosaurids and azendohsaurids) are known from Middle Triassic to Upper Triassic terrestrial deposits in Madagascar, Morocco, India, the United Kingdom, southeastern Canada, and the southwestern United States. In western Texas, trilophosaurids and malerisaurine azendohsaurids co-occur in Otischalkian sites, but numerous sites in the Chinle Formation-Dockum Group depobasin of Texas, New Mexico, and Arizona preserve either trilophosaurids or malerisaurines, blurring our understanding of the evolution of these groups and their potential biostratigraphic utility. Here we report an allokotosaurian assemblage from PFV 410 (the Kaye Quarry), a lowermost Revueltian locality in the upper Sonsela Member of the Chinle Formation at Petrified Forest National Park that preserves both trilophosaurid and malerisaurine azendohsaurid taxa, which indicates that these lineages may have co-occurred in the southwestern United States for ~10 million years during the Carnian to Norian. This locality is important because it preserves teeth of *Trilophosaurus phasmalophos* in a maxilla that may help resolve taxonomic uncertainty in that genus, and it shows that malerisaurines persisted at least for some time after the hypothesized Adamanian-Revueltian biotic turnover.

Keywords: Trilophosauridae; Malerisaurinae; Chinle Formation; Biostratigraphy.

INTRODUCTION

The Upper Triassic terrestrial assemblages from the Chinle Formation and Dockum Group of the southwestern United States include a significant number of non-archosauriform archosauromorphs, principally allokotosaurs (trilophosaurids and azendohsaurids; Gregory, 1945; Spielmann et al., 2008; Hégron et al., 2020; Nesbitt et al., 2021; Marsh et al., 2022) and tanystropheids (Pritchard et al., 2015; Lessner et al., 2018). Recently, allokotosaurs have received renewed research attention as enigmatic taxa were attributed to the group (Sues, 2003; Flynn et al., 2010, Pritchard and Sues, 2019; Chambi-Trowell et al., 2022; Foffa et al., 2023) and as new species have been discovered (Kligman et al., 2020; Marsh et al., 2022). Once considered 'cotylosaurs' or 'protorosaurs' (Case, 1928; Chatterjee, 1980), we can now recognize and identify even fragmentary remains of these extinct lineages owing to their near-global distribution in the last 40 million years of the Triassic Period as well as monodominant bonebeds that provide examples of nearly every skeletal element (Gregory, 1975; Nesbitt et al., 2015, Sengupta et

al., 2017; Marsh et al., 2022).

In the southwestern United States (Fig. 1; Appendix 1), trilophosaurids are present in the Middle Triassic Holbrook Member of the Moenkopi Formation in Arizona (*Anisodontosaurus greeri* Welles, 1947; Foffa et al., 2023), the Otischalkian (*sensu* Martz and Parker, 2017) Upper Triassic of the Colorado City Formation of western Texas (*Trilophosaurus buettneri* Case, 1928; *Trilophosaurus jacobsi* Murry, 1987/*Spinosuchus caseanus* Huene, 1932), the Adamanian Upper Triassic Tecovas Formation and middle Cooper Canyon Formation of western Texas (*T. jacobsi*/*S. caseanus*; Spielmann et al., 2008; Nesbitt et al., 2015; Kligman et al., 2020; *Trilophosaurus dornorum* Mueller and Parker, 2006; Martz et al., 2013) and the Blue Mesa Member and lower part of the Jim Camp Wash beds (Sonsela Member) of the Chinle Formation of Arizona (*Trilophosaurus dornorum*, Mueller and Parker, 2006; *Trilophosaurus* spp.; Kligman, 2023), and the lowermost part of the Revueltian Upper Triassic of the Jim Camp Wash beds (Sonsela Member) in Arizona (*Trilophosaurus phasmalophos* Kligman et al., 2020). In the same region, malerisaurine azendohsaurids are absent (to date) in the Middle Triassic Moenkopi Formation, but other azendohsaurids are present in the Middle Triassic of India and potentially Madagascar (*Pamelaria dolichotrachela* Sen, 2003, *Shringasaurus indicus* Sengupta et al., 2017, and *Azendohsaurus madagaskarensis* Flynn et al., 2010), present in the Otischalkian Upper Triassic of the Colorado City Formation of western Texas (*Malerisaurus langstoni* Chatterjee, 1986/*Otischalkia elderae* Hunt and Lucas, 1991), and the Adamanian Upper Triassic Garita Creek Formation of New Mexico (Hégron et al., 2020), Tecovas Formation of western Texas (Nesbitt et al., 2021), and Blue Mesa Member of the Chinle Formation in Arizona (*Puercosuchus traverorum* Marsh et al., 2022). Malerisaurines were thought to be absent in the Revueltian holochron or were only found in one locality at Revuelto Creek, NM (Speilmann et al., 2013), potentially representing a lineage that did not survive the Adamanian-Revueltian biotic turnover (Parker and Martz, 2010; Kligman et al., 2020; Marsh et al., 2022). Here, we identify recently collected specimens belonging to indeterminate allokotosaurians, trilophosaurids (including *Trilophosaurus phasmalophos*), and malerisaurines from a multitaxic bonebed in the lowermost Revueltian strata of the Jim Camp Wash beds (Sonsela Member, Chinle Formation) at Petrified Forest National Park. This site, published previously for its shuvosaurid, drepanosauromorph, and ornithodiran fossils (Sidor et al., 2018; Goncalves and Sidor, 2019; Marsh and Parker, 2020), contains one of the few allokotosaurian assemblages preserving material referrable both trilophosaurids and azendohsaurids, as well as the only unambiguous malerisaurine azendohsaurid currently known from the Revueltian.

MATERIALS AND METHODS

Color photographs were taken using a Nikon D90 digital camera equipped with a Nikon AF-S NIKKOR 24–85 mm lens. Image stacking was performed using Adobe Photoshop (25.0.0). When possible, identifications below are made using apomorphies of the respective clade (e.g., Nesbitt and Stocker, 2008; Bell et al., 2010; Martz et al., 2013; Lessner et al., 2018). Otherwise, identifications are made here by exclusion; only a few specimens of tanystropheids and *Vancleavea*

campi Long and Murry, 1995 have been found despite hundreds of specimens collected and prepared from PFV 410. The anatomy of the non-allokotosaurian archosauromorphs at PFV 410 is sufficiently different than what is described below that the following can be referred to the Allokotosauria until disproven with future fossil discoveries. There has yet to be a non-malerisaurine azendohsaurid found in the Chinle Formation and Dockum Group (Nesbitt et al., 2021), so we assume that specimens with azendohsaurid features are also likely malerisaurines. This is emphasized by traits found in the malerisaurine specimens of PFV 410 that are not present in non-malerisaurine azendohsaurids, as described below (Nesbitt et al., 2021; Marsh et al., 2022; Sengupta et al., 2024). The specimens discussed here were collected at Petrified Forest National Park by teams from the University of Washington under Scientific Research and Collecting permits (Study #: PEFO-00085). They are catalogued with both PEFO and UWBM specimen numbers and each is provided here, as required by U.S. National Park Service policy.

We follow Nesbitt et al. (2021) in considering '*Otischalkia elderae*' Hunt and Lucas, 1991 a robust malerisaurine azendohsaurid, if not *Malerisaurus langstoni* Chatterjee, 1986 itself, when present in the TMM Otis Chalk quarries. The distal ends of humeri from the Bull Creek Formation of eastern New Mexico (UMMP 7441 and NMMNH P-4686; Spielmann et al., 2013: fig 1a–l) were referred to '*Otischalkia elderae*' when those authors considered that taxon to represent a rhynchosaur, but here we refer to them as indeterminate malerisaurines until we can observe them in person. Regardless of whether *Trilophosaurus dornorum* (Mueller and Parker, 2006) can be differentiated from *Trilophosaurus jacobsi* Murry, 1987 (e.g., Spielmann et al., 2008) or if *T. jacobsi* Murry, 1987 is a likely junior synonym of *Spinosuchus caseanus* Huene, 1932 (e.g., Nesbitt et al., 2015), we choose to differentiate these species names in the text for clarity until a future study thoroughly evaluates the taxonomy of the genus-level clade *Trilophosaurus* and its close relatives in the context of the wealth of recent data and newly-recognized trilophosaurid taxa (Pritchard and Sues, 2019; Kligman et al., 2020; Chambi-Trowell et al., 2022; Foffa et al., 2023; Kligman, 2023; Sues et al., 2022; Sues and Schoch, 2023; Marsh et al., 2024). Below, we provide catalog numbers for comparative specimens we have observed in person or via photographs and provide the appropriate citation for literature-based comparisons.

Institutional Abbreviations — **FMNH**, Field Museum of Natural History, Chicago, IL, U.S.A.; **GR**, Ruth Hall Museum of Paleontology at Ghost Ranch, Abiquiu, NM, U.S.A.; **ISIR**, Statistical Institute, Reptiles, Kolkata, India; **MNA**, Museum of Northern Arizona, Flagstaff, AZ, U.S.A.; **IITKGPR**, Indian Institute of Technology Kharagpur, Kharagpur, India; **IVPP**, Institute for Ver tebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing, China; **MNHN**, Muséum National d'Histoire Naturelle, Paris, France; **PEFO**, Petrified Forest National Park, Petrified Forest, AZ, U.S.A. (**PFV**, Petrified Forest vertebrate locality); **PIMUZ**, Paläontologisches Institut und Museum der Universidäd Zürich, Zurich, Switzerland; **TMM**, Texas Vertebrate Paleontology Collections, University of Texas Austin, Austin, TX, U.S.A.; **TTU**, Museum of Texas Tech University, Lubbock, TX, U.S.A., (**MOTT**, Museum of Texas

Tech locality); **UA**, Université d'Antananarivo, Antannanarivo, Madagascar; **UCMP**, University of California Museum of Paleontology, Berkeley, CA, U.S.A.; **UMMP**, University of Michigan Museum of Paleontology, Ann Arbor, MI, U.S.A.; **UWBM**, Burke Museum of Natural History and Culture, University of Washington, Seattle, WA, U.S.A.; **YPM**, Yale Peabody Museum, Yale University, New Haven, CT, U.S.A.

LOCALITY INFORMATION

Locality. — PFV 410/UWBM C2226 (Kaye Quarry), near Blue Mesa and Cedar Tank, Petrified Forest National Park (Fig. 1; Marsh and Parker, 2020: fig. 2b).

Stratigraphy. — Jim Camp Wash beds, Sonsela Member, Chinle Formation (Martz and Parker, 2010).

Age. — Late Triassic, Norian (Martz and Parker, 2010), ~213–215 Ma (Nordt et al., 2015; Ramezani et al., 2011; Rasmussen et al., 2020). Revueltian holochronozone (*sensu* Martz and Parker, 2017) based on a *Machaeroprosopus* skull (PEFO 54782/UWBM 120720) discovered in 2022 and found 0.5–1.0 m below the level of the quarry from about 30 meters away (*contra* Goncalves and Sidor, 2019). The Kaye Quarry itself is approximately 1.0–1.5 m below a silicified plant debris horizon cropping out extensively laterally known as the 'persistent red silcrete zone' that may approximate the Adamanian-Revueltian boundary at PEFO (Martz and Parker, 2010).

Sedimentology. — The locality consists of two major facies: 1) a purple overbank siltstone mottled with pale greenish yellow reduction halos that are often found around vertebrate bones; and 2) a white well-cemented conglomerate lens full of extra-basinal clasts and siltstone rip-ups that discontinuously incises into the purple silt stone (Sidor et al., 2018).Vertebrate bones are distributed throughout both facies, articulation is extremely rare, and most elements are disassociated.

Vertebrate assemblage. — PFV 410/UWBM C2226 is a multitaxic bonebed comprising at least 13 taxa, including metoposaurid temnospondyls, allokotosaurian and tanystropheid archosauromorphs, the archosauriform *Vancleavea campi*, phytosaurs, pseudosuchians, and ornithodirans (Sidor et al., 2018). This is the type locality of the drepanosauromorph *Ancistronychus paradoxus* Goncalves and Sidor (2019), represented by more than a dozen unguals from the second manual digit (holotype PEFO 42805/UWBM 117331). The site also includes a diverse ornithodiran fauna (Marsh and Parker, 2020), including a lagerpetid pterosauromorph (PEFO 42397/UWBM 116823), a silesaurid dinosauriform (PEFO 39373/UWBM 108379), a dinosaur in the *Chindesaurus bryansmalli* Long and Murry (1995)/*Tawa hallae* Nesbitt et al. (2009a) clade (PEFO 39273/UWBM 108212), and a neotheropod (PEFO 39421/UWBM 108881). Most notable, PFV 410/UWBM C2226 preserves hundreds of bones belonging to at least 21 individuals of a new species of shuvosaurid pseudosuchian (Sidor et al., 2018; Armour Smith et al., 2022).

SYSTEMATIC PALEONTOLOGY

ARCHOSAUROMORPHA Huene, 1946 *sensu* Benton, 1995

ALLOKOTOSAURIA

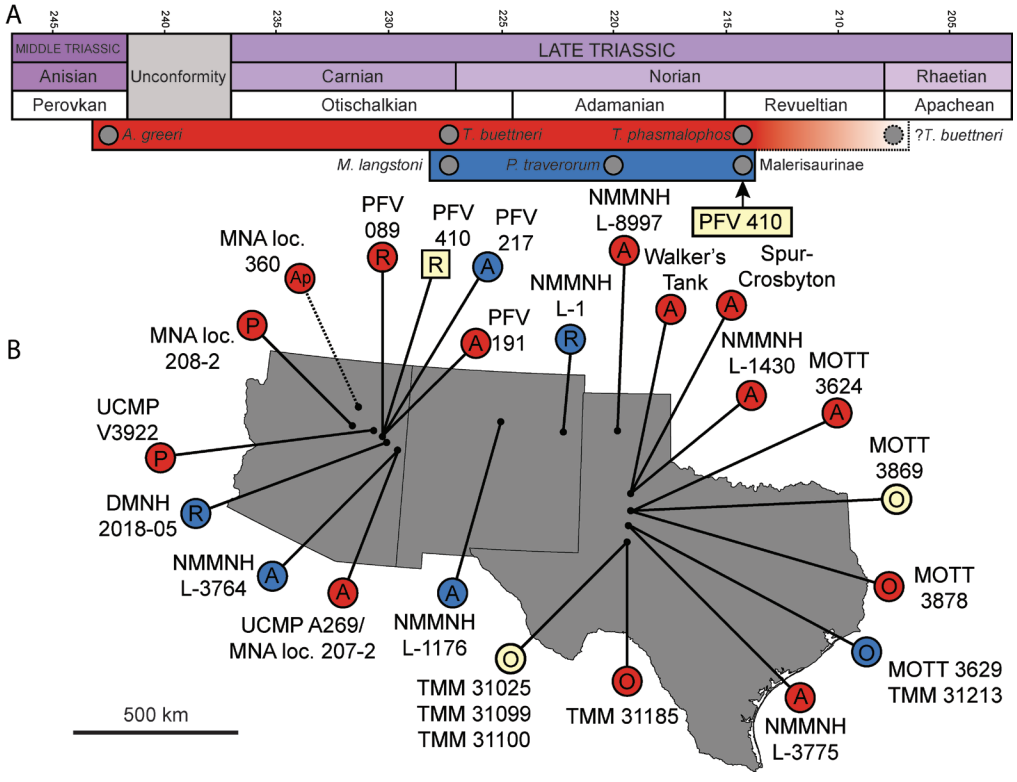


FIGURE 1. Geology and geography of selected allokotosaurians. A. Stratigraphic distribution of major localities that include trilophosaurids and malerisaurine azendohsaurids in the southwestern United States. B. Geographic distribution of major localities that include trilophosaurids and malerisaurine azendohsaurids in the southwestern United States. Red indicates trilophosaurids, blue indicates malerisaurines, and yellow indicates the presence of both at the same locality. Dashed lines indicate questioned occurrences. Map by Free Vector Maps: http://freevectormaps.com. Abbreviations: **A**, Adamanian; **Ap**, Apachean; **loc.**, fossil locality; **O**, Otischalkian; **P**, Perovkan; **R**, Revueltian.

Nesbitt, et al. 2015

Fig. 2

Voucher specimens. — PEFO 42757/UWBM 117283, left femur (Fig. 2A–F); PEFO 39375/UWBM 108381 (Fig. 2G–L), right tibia.

Rationale for identification. — The femur is sigmoidal in ventral view, has well-developed condyles distally, and has a prominent internal trochanter similar to other allokotosaurs like *Pamelaria dolichotrachela* Sen, 2003 (ISIR 316/55), *Azendohsaurus laaroussi* Dutuit, 1972 (MNHN-ALM 498/502, Cubo and Jalil, 2019), and *Trilophosaurus buettneri* (TMM 31025-140). The internal trochanter reaches the proximal end of the element (Fig. 2B) similar to *Malerisaurus robinsonae* (ISIR 150) and *Malerisaurus langstoni* (TMM 31099-11), some specimens of *Puercosuchus traverorum* (PEFO 44186; NMMNH P-60208), and and some *Trilophosaurus buettneri*

specimens from TMM 31025 (Marsh et al., 2022). Nesbitt et al. (2021: fig. 7a) suggested that trilophosaurid and azendohsaurid femora can be differentiated on the proportion of the width of the femoral head to the maximum length of the femur, but the relatively short length (~111 mm) of PEFO 42757/UWBM 117283 occurs within the region of overlap in this proportion between the two clades.

The tibia PEFO 39375/UWBM 108381 is arched anteriorly like that of other allokotosaurs (e.g., *Azendohsaurus madagaskarensis*, FMNH PR 3814, Nesbitt et al., 2015). In proximal view, the proximal condyles are separated posteriorly by relatively deep concavity (Fig. 2K), similar to that of *Puercosuchus traverorum* (PEFO 44203) but not *Trilophosaurus buettneri* (TMM 31025-140). Unlike *Puercosuchus traverorum* (PEFO 44203), *Malerisaurus robinsonae* (ISIR 150), and *Malerisaurus langstoni* (TMM 31099-11), the tibia PEFO 39375/UWBM 108381 lacks the low tubercle on the medial side just below the proximal medial condyle (Marsh et al., 2022: fig. 16.13), similar to the tibiae of non-malerisaurine azendohsaurids (FMNH PR 2749) and *Trilophosaurus buettneri* (TMM 31025-140).

The non-allokotosaurian non-archosaur archosauromorphs at PFV 410 include tanystropheids and *Vancleavea campi*. The allokotosaur femur PEFO 42757/UWBM 117283 has a strong internal trochanter which is present in tanystropheids (TTU-P11344) but absent in *Vancleavea campi* (PEFO 2427). Unlike the allokotosaur tibia PEFO 39375/UWBM 108381 in which the proximal condyles are separated by a posterior groove, that margin is straight in *Vancleavea campi* (PEFO 2427) and is not well documented in tanystropheids. Considering that there is no unambiguous feature that would differentiate these two specimens between trilophosaurid and azendohsaurids, we can only refer these to Allokotosauria.

TRILOPHOSAURIDAE Gregory, 1945
sensu Nesbitt et al., 2015

Fig. 3A–J

Voucher specimens. — PEFO 39521/UWBM 109860, right postorbital (Fig. 3A); PEFO 54629/UWBM 120532, right fifth metatarsal (Fig. 3B–D); PEFO 39554/UWBM 109893, partial left calcaneum (Fig. 3E–H); PEFO 47371/UWBM 119655, cervical vertebra (Fig. 3I); PEFO 54931/UWBM 124160, five articulated posterior cervical vertebrae (Fig. 3J).

Rationale for identification. — The postorbital is triradiate and includes a prominent curved rim around the posterior margin of the orbit (Fig. 3A). In *Pamelaria dolichotrachela* (ISIR 316/1, Sen, 2003) and *Puercosuchus traverorum* (PEFO 47823), the lateral surface of the postorbital forms an isosceles triangle with the more acute apex pointing ventrally, whereas in PEFO 42365/UWBM 116791, *Trilophosaurus buettneri* (TMM 31025-140), and *Trilophosaurus jacobsi* (NMMNH P-41400) it forms more of an equilateral triangle. It lacks the bifurcated articulation with the jugal like that of *Vancleavea campi* (GR 138) and the strap-like shape found in *Tanystropheus hydroides* (PIMUZ T 2790, Spiekman et al., 2020). Like other archosauromorphs, the fifth metatarsal is hook-shaped and forms a ‘paddle’ that articulates medially with the rest of the metatarsus. The element lacks the proximal dorsal tubercle found in *Puercosuchus traverorum* (PEFO 44359) and the proximal process is relatively long like that of *Trilopho-*

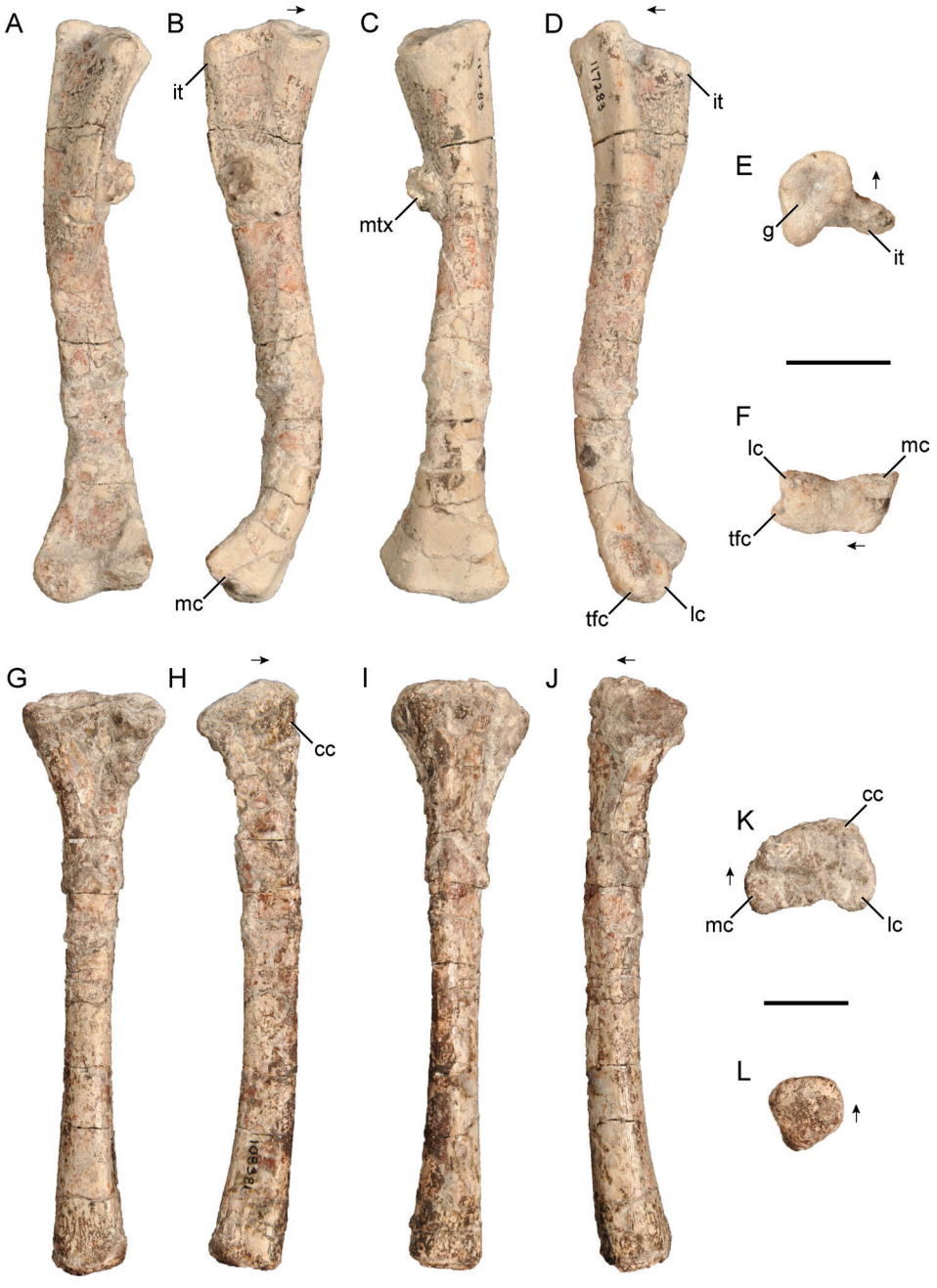


FIGURE 2. Allokotosauria specimens from the Kaye Quarry (PFV 410). A–F. PEFO 42757/UWBM 117283, left femur in A, posteroventral, B, ventral, C, anterodorsal, D, dorsal, E, proximal, and F, distal view; G–K. PEFO 39375/UWBM 108381, right tibia in G, posterior, H, lateral, I, anterior, J, medial, K, proximal, and L, distal view. Arrows point in anterior direction. Scale bars = 2 cm. Abbreviations: **cc**, cnemial crest; **g**, groove; **it**, internal trochanter; **lc**, lateral condyle; **mc**, medial condyle; **mtx**, matrix; **tfc**, tibiofibular crest.

saurus buettneri (TMM 31025). It has a ridge on the dorsolateral margin of the distal end (Fig. 3B) like that in *Trilophosaurus buettneri* (TMM 31025-140), *Azendohsaurus madagaskarensis* (FMNH PR 2776), and *Puercosuchus traverorum* (PEFO 44359).

Like metatarsal V of *Trilophosaurus buettneri*, in which the ratio of the mediolateral width to proximodistal length is 0.66, that of PEFO 54629/UWBM 120532 is 0.67, unlike the relatively shorter fifth metatarsal of *Puercosuchus traverorum* (0.88; PEFO 44359). This specimen is proximodistally shorter compared to its mediolateral width in *Vancleavea campi* (GR 138) and the tanystropheid *Macrocnemus fuyuanensis* (IVPP V 15001, Scheyer et al., 2020).

The calcaneum PEFO 39554/UWBM 109893 only preserves the proximolateral portion, so the shape of the distal and medial edges cannot be estimated. In proximal view (Fig. 3G), both articular surfaces for the astragalus are present. In ventral view (Fig. 3F), the angle formed by the articular surface for distal tarsal 4 and the dorsal articular surface for the astragalus is similar to that of *Trilophosaurus buettneri* (TMM 31025-140) in that it is much less acute than that of *Puercosuchus traverorum* (PEFO 44141) and the tanystropheid *Macrocnemus fuyuaensis* (IVPP V 15001, Spiekman et al., 2020). The calcaneum of *Vancleavea campi* is a more simple paddle-shaped element (GR 138, Nesbitt et al., 2009).

The middle cervical vertebra PEFO 47371/UWBM 119655 (Fig. 3I) is similar to other allokotosaurs in that the diapophysis and parapophysis are situated close to one anther on the anterior end of the centrum, and the latter has a longitudinal ridge extending posteriorly. The neural spine is tall (unlike the middle to posterior cervical vertebrae of the tanystropheid *Tanytrachelos ahynis*, YPM 7496, Olsen, 1979) and inclined anterodorsally but lacks the lateral dorsal expansion found in the malerisaurines *Puercosuchus traverorum* (PEFO 43992) and *Malerisaurus robinsonae* (ISIR 150, Sengupta et al., 2024). The posterior articular surface of the centrum has a shallow concave center surrounded by a raised rim and is not as convex as the cervical vertebrae of *Trilophosaurus buettneri* (TMM 31025-140) or *Trilophosaurus jacobsi* (NMMNH P-44274).

The articulated vertebrae PEFO 54931/UWBM 124160 (Fig. 3J) are considered posterior cervical vertebrae because the parapophysis is on the centrum in each of the vertebrae and the diapophysis moves from being on a short process near the parapophysis on the anterior portion of the centrum to a laterally-projecting stalk near the midpoint of the centrum. The anteriormost centrum is similarly shaped to PEFO 47371/UWBM 119655 described above (Fig. 3I), and it exhibits the same anatomical features that identify it to the Trilophosauridae. In cross section near the dorsal end of the neural spine, the anteriormost vertebra is blade-like, but in each successive posterior the spine expands slightly such that the posteriormost vertebra is cruciform in shape (Fig. 3J). This shape is different than that found in the same region of the malerisaurine *Puercosuchus traverorum* (e.g., PEFO 44265, Marsh et al., 2022) in which the lateral expansions are separated from the main body of the neural spine by sharp clefts. Dorsal expansions of the posterior cervical neural spines are not documented in any species of *Trilophosaurus*, but they are found in *Azendohsaurus madagaskarensis* (e.g., UA 8-30-98-349, Nesbitt et al., 2015) and *Shringasaurus indicus* (ISIR 803, Sengupta and Bandyopadhyay, 2022). Unaccounted-for

elaboration of trilophosaurid neural spines is possible, however, as those of *Spinosuchus caseanus* (Spielmann et al., 2009) are known for a radical anatomical departure from the plesiomorphic archosauromorph condition.

TRILOPHOSAURUS PHASMALOPHOS Kligman et al., 2020

Figs. 3K–N

Voucher specimens. — PEFO 47420/UWBM 119740, isolated tooth (Fig. 3K–L); PEFO 42365/UWBM 116791, left maxilla (Fig. 3M–N).

Rationale for identification. —Previously, the only specimens known from this taxon were isolated teeth, diagnosed by a unique combination of characters and autapomorphies (the latter are marked with an asterisk below; Kligman et al., 2020: p. 28): "a crown base labiolingually wider than mesiodistally long (a 1:5 mesiodistal length to labiolingual width ratio) with two distinct cusps instead of three*; the tips of the cusps are slightly recurved lingually*; both cusps bear apicolingually-facing cingula on their mesial and distal margins, with two symmetrical cingula on the mesial and distal sides of the lingual cusp, one cingulum on the mesial margin of the labial cusp, and two superimposed cingula on the distal margin of the labial cusp, totaling five cingula per tooth*." All these features are present in PEFO 47420/UWBM 119740 (Fig. 3K) and the posterior two teeth of PEFO 42365/UWBM 116791 (Fig. 3M), allowing the specimen to be referred to *Trilophosaurus phasmalophos*. However, the three anterior partially preserved teeth clearly have three cusps (Fig. 3M) and some of the apomorphies listed above. It seems that moving anteriorly, the central ridge extending lingually from the lingual cusp becomes more prominent apically, eventually forming an additional, more lingual cusp. This specimen will be important in understanding serial variation in some trilophosaurid teeth, especially with similar variation present in earlier-diverging members of the clade (Chambi-Trowell et al., 2021; Foffa et al., 2023).

AZENDOHSAURIDAE Nesbitt et al., 2015

MALERISAURINAE Nesbitt et al., 2021

Figs. 4–5

Voucher specimens. — PEFO 46902/UWBM 118796, right premaxilla (Fig. 4A); PEFO 39376/UWBM 108382, left maxilla (Fig. 4C); PEFO 47450/UWBM 119770, right prefrontal (Fig. 4E); PEFO 39556/UWBM 109895, ventral end of left quadrate (Fig. 4F–G); PEFO 39558/UWBM 109897, ventral end of left quadrate (Fig. 4H–I); PEFO 39429/UWBM 108889, left humerus (Fig. 5A–F); PEFO 39436/UWBM 108896, proximal end of left ulna (Fig. 5G–H); PEFO 39544/UWBM 109883, partial right astragalus (Fig. 5I–K); PEFO 47459/UWBM 119779, ungual (Fig. 5L–O).

Rationale for identification. — Unlike *Trilophosaurus buttneri* (TMM 31025-207), the premaxilla bears teeth and lacks a 'beak.' It is very similar to those of malerisaurines (e.g., PEFO 43914, TTU-P11212) and other azendohsaurids (e.g., *Shringasaurus indicus*, ISIR 793, Sengupta and Bandyopadhyay, 2022) in that the posterodorsal process is relatively long and it lacks an anterodorsal process (Nesbitt et al., 2021; Marsh et al.,

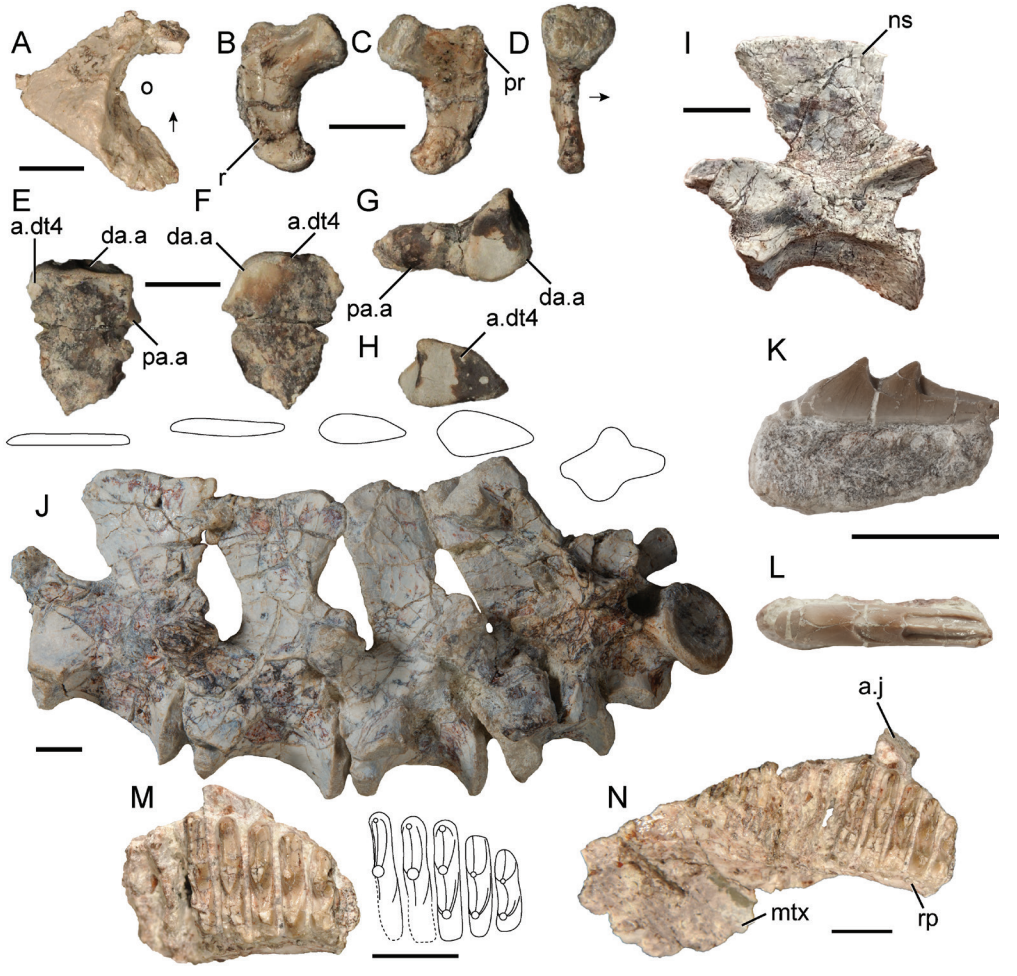


FIGURE 3. Trilophosaurid specimens from the Kaye Quarry (PFV 410). A. PEFO 39521/UWBM 109860, trilophosaurid right postorbital in lateral view; B–D. PEFO 54629/UWBM 120532, trilophosaurid right metatarsal V in B, dorsal, C, ventral, and D, proximal view; E–H. PEFO 39554/UWBM 109893, partial trilophosaurid left calcaneum in E, dorsal, F, ventral, G, proximal, and H, medial view; I. PEFO 47371/UWBM 119655, trilophosaurid middle cervical vertebra in left lateral view; J. PEFO 54931/UWBM 124160, five posterior neck vertebrae in lateral view with interpretive drawings of the dorsal cross sections of the each neural spine; K–L; PEFO 47420/UWBM 119740, *Trilophosaurus phasmalophos* tooth in K, distal and L, occlusal view; M–N. PEFO 42365/UWBM 116791, *Trilophosaurus phasmalophos* left maxilla in M, occlusal view with interpretive line drawing and N, ventral view. Arrows point in dorsal direction. Scale bars = 1 cm. Abbreviations: **a.j**, articular surface with jugal; **a.dt4**, articular surface for distal tarsal 4; **da.a**, distal articular surface for astragalus; **mtx**, matrix; **ns**, neural spine; **o**, orbit; **pa.a**, proximal articular surface for astragalus; **pr**, proximal process; **rp**, resorption pit.

2022). The premaxilla in tanystropheid *Tanystropheus hydroides* also lacks an anterodorsal process, but the element is anteroposteriorly longer compared to its dorsoventral height in that taxon (PIMUZ T 2790, Spiekman et al., 2020). The archosauriform *Vancleavea campi* has an anterodorsal process that separates the external nares medially (GR 138). The single tooth preserved in PEFO 46902/UWBM 118796 is slightly procumbent like that of *Azendohsaurus madagaskarensis* (FMNH PR 2751) and *Puercosuchus traverorum* (PEFO 43914). The angle formed by the ventral margin of the element and the posterodorsal process is relatively steep in PEFO 46902/UWBM 118796 (33°; Fig. 4A) compared to the more acute angle present in *Puercosuchus traverorum* (14°, PEFO 43914; Fig 4B).

The maxilla preserves a prominent posterodorsal process with a posteroventral concavity (Fig. 4C), shared in *Azendohsaurus laaroussii* (MNHN-ALM 355-3, Dutuit, 1972), *Azendohsaurus madagaskarensis* (FMNH PR 2751), and malerisaurines (e.g., PEFO 43914).

The overall shape of the maxilla is more similar to that of tanystropheids (e.g., PIMUZ T 2790) than that *Vancleavea campi* which lacks a long anterior process (GR 138), but the teeth of tanystropheids are not ankylothecodont like those of allokotosaurs. Unlike trilophosaurids and non-malerisaurine azendohsaurids, PEFO 39376/UWBM 108382 preserves triangular, labiolingually compressed teeth with fine serrations and apical recurvature, like other malerisaurines (Nesbitt et al., 2011). However, unlike in *Puercosuchus traverorum* (PEFO 43914; Fig. 4D), the teeth in PEFO 39376/UWBM 108382 are all the same basic shape (Fig. 4C). Whether this indicates an autapomorphy of a new taxon or a plesiomorphy of malerisaurines is uncertain, as the holotype specimen of *Malerisaurus langstoni* (TMM 31099-11) and hypodigm of *Malerisaurus robinsonae* (ISIR 150, ISIR 151) do not preserve maxillary teeth.

The prefrontal is triradiate and forms the anterodorsal margin of the orbit, like in other reptiles (Fig. 4E). Like *Azendohsaurus madagaskarensis* (FMNH PR 2751) and *Puercosuchus traverorum* (PEFO 43991), the dorsolateral margin is thickened and slightly rugose, unlike the relatively smooth but still thickened margin found in *Trilophosaurus buettneri* (TMM 31025-143) and *Trilophosaurus jacobsi* (NMMNH P-41400). The orbital rim of the prefrontal of some tanystropheids (e.g., PIMUZ T 2790, Spiekman et al., 2020) and *Vancleavea campi* (GR 138) is sharp rimmed rather than thickened. The two ventral ends of the quadrate are typical of those of azendohsaurids (e.g., *Azendohsaurus madagakarensis*, FMNH PR 2751, *Pamelaria dolichotrachela*, ISIR 328/1, Sen, 2003; Nesbitt et al., 2021) in that they are asymmetrical (unlike *Trilophosaurus buettneri*, TMM 31025-140), such that the posterior condyle is offset ventrally from the rest of the articular surface (Fig. 4F–I).

The humerus is expanded mediolaterally both proximally and distally like that of azendohsaurids (Nesbitt et al., 2021); unfortunately, the midshaft is missing, preventing the calculation of the ratio of the proximal width to the total length to better differentiate it between a malerisaurine and a trilophosaurid (sensu Nesbitt et al., 2021: fig. 7b). Luckily, the specimen preserves features found only in azendohsaurids (e.g., *Azendohsaurus madagaskarensis*, FMNH FR 3816; '*Otischalkia elderae*', TMM 31025-263; *Puercosuchus traverorum*, PEFO 38627) like a prominent supinator crest distally

(Fig. 5A), prominent proximal lateral tuberosity (Fig. 5C) that reaches the proximal extent of the humeral head TMM 31099-11, ISIR 150), and a pyramidal process on the dorsal surface next to the ectepicondyle (FMNH PR 3816, PEFO 38627, TMM 31099-11), best seen in distal view (Fig. 5F). The humeri of tanystropheids (e.g., IVPP V 15001, Scheyer et al., 2020; YPM 7496, Olsen, 1979) and *Vancleavea campi* (PEFO 34035) are much more gracile than those of allokotosaurs.

In proximal view, the ulna has a prominent concavity between the olecranon process and the anteromedial process (Fig. 5H), unlike the relatively flat margin found in *Trilophosaurus buettneri* (TMM 31025-140) and *Azendohsaurus madagaskarensis* (FMNH PR 3816), but more similar to what is found in the malerisaurines *Puercosuchus traverorum* (PEFO 44131, NMMNH P-63289). PEFO 39436/UWBM 108896 lacks the secondary ossification of the olecranon process found in some malerisaurines (Marsh et al., 2022), but the proximal surface of that process is rugose and likely had a cartilaginous articular surface. The olecranon process is much more prominent in malerisaurines than that of tanystropheids (e.g., *Macrocnemus fuyuanensis*, IVPP V 15001, Scheyer et al., 2020) and *Vancleavea campi* (PEFO 34035).

The partial astragalus only preserves the proximal half of the element, including the articular surface with the tibia and the dorsal articulation with the calcaneum (Fig. 5I–K). In distal view (Fig. 5J), the dorsal articular surface for the calcaneum is rounded like that of *Azendohsaurus madagaskarensis* (FMNH PR 2776) and *Puercosuchus traverorum* (PEFO 44140) whereas it is subtriangular in *Trilophosaurus buettneri* (TMM 31025-140). The astragalus of *Vancleavea campi* only has one articular surface for the calcaneum (GR 138, Nesbitt et al., 2009). The anterior hollow (Fig. 5I) is relatively deep like that of *Puercosuchus traverorum* (PEFO 44140) compared to that of *Trilophosaurus buettneri* (TMM 31025-140).

The ungual (Fig. 5L–O) is highly mediolaterally compressed, flat along its ventral surface, and has bilateral grooves extending down the lateral and medial sides of the element. It is unclear as to whether it represents an ungual from the manus or pes, however it likely belongs to an allokotosaurian because it is much more mediolaterally compressed than those found in the ornithodiran taxa present at PFV 410 (Nesbitt et al., 2011; Marsh and Parker, 2020). In addition, it is similar to unguals in *Trilophosaurus buettneri* (TMM 31025-140) and *Azendohsaurus madagakarensis* (UA 9-8-98-497), and it clearly lacks the unique dorsoventrally compressed anatomy found in shuvosaurid pedal unguals (Nesbitt, 2007). PEFO 47459/UWBM 119779 has a prominent flexor tubercle like that of *Trilophosaurus buettneri* (TMM 31025-140), but like that of *Azendohsaurus madagaskarensis* (UA 9-8-98-497) the tubercle is positioned more distal to the proximal articular surface (Nesbitt et al., 2015). The angle of curvature (*sensu* Feduccia, 1993) of PEFO 47459/UWBM 119779 is 100°, which is more similar to that of *Azendohsaurus madagaskarensis* (95°–125°; Nesbitt et al., 2015) than *Trilophosaurus buettneri* (106°–155°; Spielmann et al., 2008). At the time of publication of Marsh et al. (2022), no unguals were known from *Puercosuchus traverorum*, but a few have now been recovered and prepared from the type locality (PEFO 44138, PEFO 44139, PEFO 44343, PEFO 47777, PEFO 52337). These range in angle of curvature from 60°–105° (overlapping with that of PEFO 47459/

UWBM 119779), and like what was noted for *Azendohsaurus madagaskarensis* (Nesbitt et al., 2015), the angle tends to be higher in larger unguals of *Puercosuchus traverorum*. The angle of curvature is much less in tanystropheids (e.g., *Macrocnemus fuyuanensis*, IVPP V 15001, Scheyer et al., 2020) but is not documented for *Vancleavea campi*.

DISCUSSION

Prior to the discovery of both trilophosaurids and malerisaurine azendohsaurids in PFV 410 at Petrified Forest National Park, both clades were only found together in two Otischalkian localities in western Texas (Fig. 1B; Appendix 1): 1) three of the Otis Chalk quarries in Howard County (Quarry 1: TMM 31025; Quarry 2: TMM 31099; Quarry 3; TMM 31100), which preserve both *Trilophosaurus buettneri* (e.g., TMM 31025-140) and *Malerisaurus langstoni* (i.e., TMM 31099-11) in the Colorado City Formation; and 2) MOTT 3869 (Boren Quarry) in the lower part of the Cooper Canyon Formation in Garza County, which preserves *Trilophosaurus dornorum* (e.g., TTU-P10413) and a malerisaurine (e.g., TTU-P10515). Depending on whether or not *Trilophosaurus jacobsi* is a junior synonyn of *Spinosuchus caseanus* (Nesbitt et al., 2015), each trilophosaurid-only locality contains a single trilophosaurid taxon (with the exception of NMMNH L-1430 in the Tecovas Formation of Crosby County, Texas, which preserves both *Trilophosaurus buettneri* and *Trilophosaurus jacobsi*; Spielmann et al., 2018), a pattern that seems to be paralleled in malerisaurine-only localities, again, depending on if '*Otischalkia elderae*' is a large morph of *Malerisaurus langstoni* in the Otis Chalk quarries of Howard County, Texas (Nesbitt et al., 2021).

Thus, PFV 410 represents only the third place in the southwestern United States in which trilophosaurids and malerisaurine azendohsaurids co-occur in the same locality. Not only that, but PFV 410 is Revueltian in age, meaning malerisaurines persisted after the hypothesized Adamanian-Revueltian biotic turnover (Parker and Martz, 2010) and that the two allokotosaurian lineages may have co-occurred for more than 10 Ma across the Chinle Formation-Dockum Group depobasin (Fig. 1A). Both clades seem to disappear early in the Revueltian as they are present in a handful of sites in the upper part of the Jim Camp Wash beds of the Sonsela Member (Chinle Formation; Kligman et al., 2020; this study). However, there is a disputed occurrence of a fragmentary *Trilophosaurus buettneri* tooth (MNA V7064) from the Apachean Owl Rock Member on Ward Terrace, Arizona (MNA loc. 360; Kirby, 1991). Some authors question the trilophosaurid affinities of this specimen and its collection methodologies (e.g., Heckert et al., 2006), but given the regional Middle Triassic occurrences (Foffa et al., 2023) and high recovery of trilophosaurid teeth through much of the Chinle Formation (Mueller and Parker, 2006; Spielmann et al., 2008; Kligman et al., 2022), only increased microvertebrate sampling of Owl Rock Member localities will help to determine if trilophosaurids persisted into the Apachean.

A survey of the lithologies and depositional environments of global allokotosaur occurrences is beyond the scope of this contribution, but such a treatment may provide some insight on any environmental, biogeographic, or paleobio logical reasons that azendohsaurids and trilophosaurids do not co-occur more

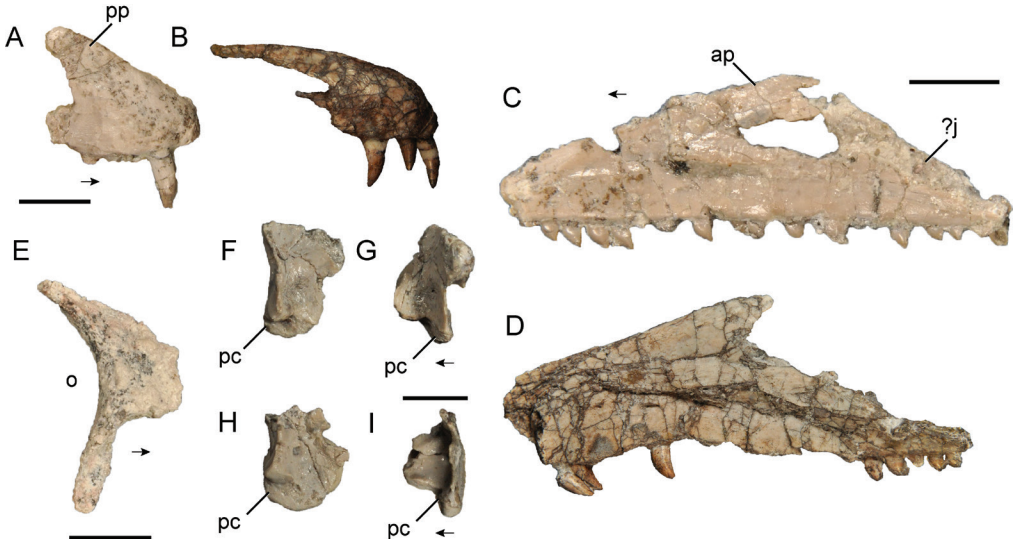


FIGURE 4. Malerisaurine cranial specimens. A. PEFO 46902/UWBM 118796, right premaxilla in lateral view; C. PEFO 39376/UWBM 108382, left maxilla in lateral view; E. PEFO 47450/UWBM 119770, right prefrontal in lateral view; F–G. PEFO 39556/UWBM 109895, ventral end of left quadrate in F, anterior and G, medial view; H–I. PEFO 39558/UWBM 109897, ventral end of left quadrate in H, anterior and I, medial view. B. Comparative holotype right premaxilla of *Puercosuchus traverorum* (PEFO 43914) in lateral view. D. Comparative holotype right maxilla of *Puercosuchus traverorum* (PEFO 43914, reversed) in lateral view. Arrows point in anterior direction. Scale bars = 1 cm labelled, B and D are not to scale. Abbreviations: **ap**, ascending process; **j**, jugal; **o**, orbit; **pc**, posterior condyle; **pp**, posterior process.

frequently in the fossil record. At present the observed lack of co-occurrences of these clades within the same locality is probably best explained by sampling methods. Important representative allokotosaur taxa have been described from monodominant bonebeds (e.g., *Trilophosaurus buettneri*, Gregory, 1945; *Trilophosaurus jacobsi*, Heckert et al., 2006; *Azendohsaurus madagaskarensis*, Flynn et al.2010; *Shringasaurus indicus*, Sengupta et al., 2017; *Puercosuchus traverorum*, Marsh et al., 2022). However, allokotosaurs are also known from microsites (e.g., Heckert et al., 2004; Cawthorne et al., 2024), but identified allokotosaurs from those sites have exclusively been trilophosaurids. This is likely because trilophosaurid teeth are more recognizable and divergent in anatomy to those of most other contemporary reptiles. Further, non-malerisaurine azendohsaurid teeth have been mistaken for ornithischian or sauropodomorph dinosaur teeth in the past (e.g., Dutuit, 1972; Gauffre, 1993), and those of malerisaurines have also been confused for ornithischian or sauropodomorph dinosaurs (Marsh et al., 2022) or have relatively plesiomorphic tooth shapes (see PEFO 39376/UWBM 108382 above; Fig. 4C). For example, Ray et al. (2016) referred isolated teeth from the Upper Triassic Tiki Formation of India to an “indeterminate theropod” (fig. 7c–d). However, IITKGPR404A looks remarkably similar to teeth in the he anterior regions of the maxillae and dentaries of the hypodigm

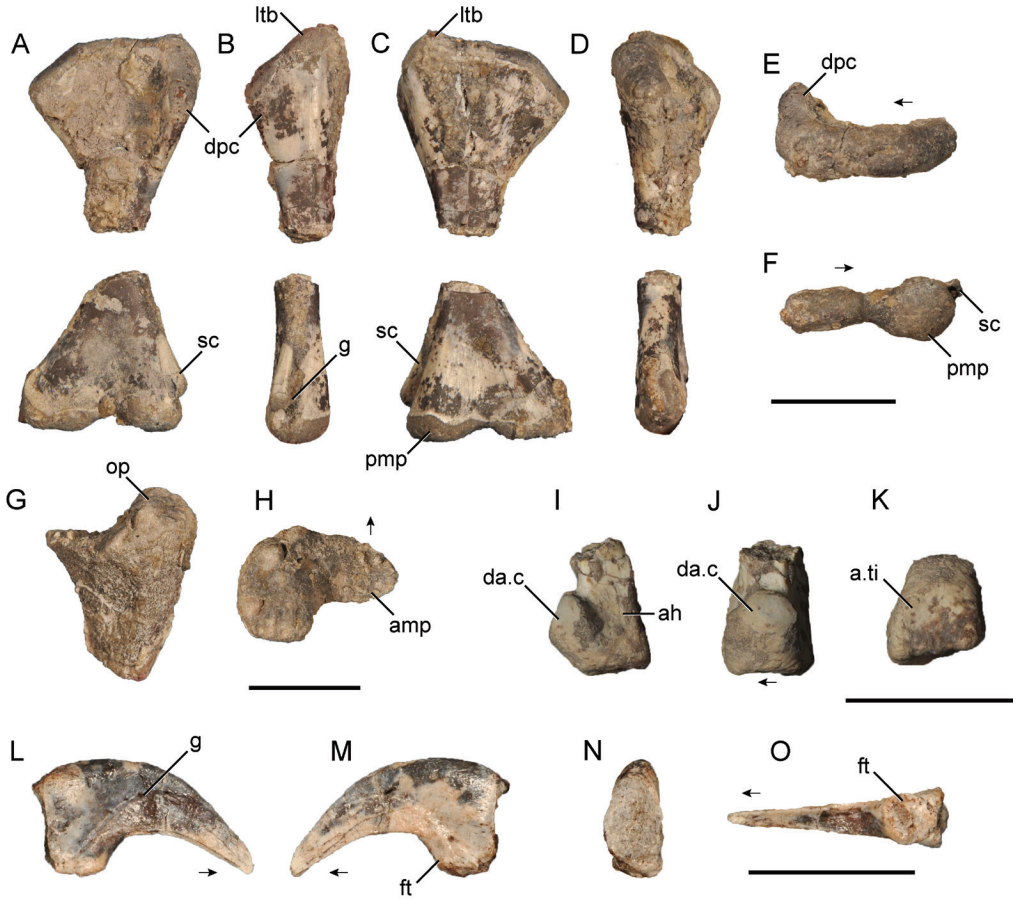


FIGURE 5. Malerisaurine postcranial specimens from the Kaye Quarry (PFV 410). A–F. PEFO 39429/UWBM 108889, left humerus in A, ventral, B, lateral, C, dorsal, D, medial, E, proximal, and F, distal view; G–H. PEFO 39436/UWBM 108896, proximal end of left ulna in G, anterior and H, proximal view; I–K. PEFO 39544/UWBM 109883, partial right astragalus in I, dorsal, J, distal, and K, medial view; L–O. PEFO 47459/UWBM 119779, ungual in L–M, medial or lateral view, N, proximal, and O, ventral view. Arrows point in anterior direction. Scale bars = 2 cm. Abbreviations: **a.ti**, articular surface for tibia; **ah**, anterior hollow; **amp**, anteromedial process; **da.c**, distal articular surface for calcaneum; **dpc**, deltopectoral crest; **ft**, flexor tubercle; **g**, groove; **ltb**, lateral tuberosity; **op**, olecranon process; **pmp**, pyramidal process; **sc**, supinator crest.

of *Puerosuchus traverorum* (e.g., PEFO 43914, PEFO 38606; Marsh et al., 2020: fig. 3), and theropod postcrania from the Tiki Formation have only been mentioned in the literature anecdotally (Chatterjee and Majumdar, 1987; Ray et al., 2016; Marsh and Parker, 2020). Finally, microvertebrate sampling of fossiliferous Upper Triassic continental deposits has vastly outpaced that of Middle Triassic units, and further sampling of the latter interval in the Moenkopi Formation of the American Southwest (Foffa et al., 2023), the Economy Member of the Wolfville Formation in Nova Scotia, Canada (Sues et al. 2022), the Erfurt Formation from southwestern Germany (Sues and Schoch, 2023), the Lifua Member of the Manda beds in Tanzania (Smith et al., 2017), and the Denwa Formation, Yerrapalli Formation, and Bhimaram Formation of India (Bandyopahhyay and Sengupta, 1999) may help recover older azendohsaurids and trilophosaurids from the same localities.

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APPENDIX 1. Major occurrences of trilophosaurid and malerisaurine azendohsaurids in the southwestern United States to accompany Figure 1. Localities are arranged in approximately stratigraphic order, with oldest sites listed first. Type localities are indicated with an asterisk.

Locality	Formation, Member, Holochronozone	State, County	Trilophosaurid taxa present	Malerisaurine taxa present	References
UCMP V3922 (Holbrook Quarry)	Moenkopi Formation, Holbrook Member, Perovkan	AZ, Navajo	*Anisodontosaurus greeri**	N/A	Welles, 1947; Foffa et al., 2023
MNA loc. 208-2 (Radar Mesa)	Moenkopi Formation, Holbrook Member, Perovkan	AZ, Coconino	*Anisodontosaurus greeri*	N/A	Welles, 1947; Foffa et al., 2023
MOTT 3869 (Boren Quarry)	lower Cooper Canyon Formation, Otischalkian	TX, Garza	*Trilophosaurus dornorum*	Malerisaurinae indet.	Parker and Mueller, 2006; Spielmann et al., 2008; Sarigül, 2017; Marsh et al., 2022
MOTT 3878 (Lott Hill)	lower Cooper Canyon Formation, Otischalkian	TX, Garza	*Trilophosaurus dornorum*	N/A	Parker and Mueller, 2006; Spielmann et al., 2008
MOTT 3629; TMM 31213 (Griffin Ranch)	lower Cooper Canyon Formation, Otischalkian	TX, Borden	N/A	Malerisaurinae indet.	Nesbitt et al., 2021
TMM 31025 (Otis Chalk Quarry 1); TMM 31099 (Otis Chalk Quarry 2); TMM 31100 (Otis Chalk Quarry 3)	Colorado City Formation, Otischalkian	TX, Howard	*Trilophosaurus buettneri*	*Malerisaurus langstoni**/ *'Otischalkia elderae'*	Gregory, 1945; Chatterjee, 1986; Nesbitt et al., 2021
TMM 31185 (Otis Chalk Quarry 3A)	Colorado City Formation, Otischalkian	TX, Howard	*Trilophosaurus buettneri*	N/A	Gregory, 1945

APPENDIX 1. (*continued*)

Locality	Formation, Member, Holochronozone	State, County	Trilophosaurid taxa present	Malerisaurine taxa present	References
NMMNH L-3775 (Kahle Quarry)	middle Cooper Canyon Formation, Adamanian	TX, Borden	*Trilophosaurus jacobsi*/ *Spinosuchus caseanus*	N/A	Spielmann et al., 2008; Nesbitt et al., 2015
MOTT 3624 (Post Quarry)	upper part of lower Cooper Canyon Formation, Adamanian	TX, Garza	*Trilophosaurus dornorum*	N/A	Parker and Mueller, 2006; Martz et al., 2013
UMMP Walker's Tank locality	Tecovas Formation, Adamanian	TX, Crosby	*Trilophosaurus buettneri**	N/A	Case, 1928
UMMP Spur-Crosbyton locality	Tecovas Formation, Adamanian	TX, Crosby	*Spinosuchus caseanus**	N/A	Von Huene, 1932; Spielmann et al., 2009; Nesbitt et al., 2015
NMMNH L-1430 (Upper Kalgary)	Tecovas Formation, Adamanian	TX, Crosby	*Trilophosaurus buettneri*; *Trilophosaurus jacobsi*	N/A	Spielmann et al., 2008
NMMNH L-8997 (Rotten Hill)	Tecovas Formation, Adamanian	TX, Potter	*Trilophosaurus jacobsi*/ *Spinosuchus caseanus*	N/A	Spielmann et al., 2009; Nesbitt et al., 2015
NMMNH L-1176 (Lamy Quarry)	lower Garita Creek Formation, Adamanian	NM, Santa Fe	N/A	Malerisaurinae indet.	Hégron et al., 2020
NMMNH L-1 (Revuelto Creek)	Bull Canyon Formation	NM, Quay	N/A	Malerisaurinae indet.	Spielmann et al., 2013
UCMP A269/ MNA loc. 207-2 (*Placerias* Quarry)	Chinle Formation, lower Sonsela Member, Adamanian	AZ, Apache	*Trilophosaurus jacobsi**	N/A	Murry, 1987; Kligman et al., 2020

APPENDIX 1. (*continued*)

Locality	Formation, Member, Holochronozone	State, County	Trilophosaurid taxa present	Malerisaurine taxa present	References
NMMNH L-3764 (Krzyzanowski bonebed)	Chinle Formation, lower Blue Mesa Member, Adamanian	AZ, Apache	N/A	*Puercosuchus traverorum*	Heckert et al., 2001; Heckert et al., 2004; Marsh et al., 2022
PFV 191 (Flag Canyon)	Chinle Formation, lower Sonsela Member, Adamanian	AZ, Apache	*Trilophosaurus dornorum**	N/A	Mueller and Parker, 2006
PFV 217 (Dinosaur Wash)	Chinle Formation, upper Blue Mesa Member, Adamanian	AZ, Apache	N/A	*Puercosuchus traverorum**	Marsh et al., 2022
DMNH 2018-05 (Green Site)	Chinle Formation, upper Sonsela Member, Revueltian	AZ, Apache	*Trilophosaurus phasmalophos*	N/A	Kligman et al., 2020
PFV 089 (Bowman Locality)	Chinle Formation, upper Sonsela Member, Revueltian	AZ, Navajo	*Trilophosaurus phasmalophos**	N/A	Kligman et al., 2020
PFV 410 (Kaye Quarry)	Chinle Formation, upper Sonsela Member, Revueltian	AZ, Apache	*Trilophosaurus phasmalophos*	Malerisaurinae indet.	Sidor et al., 2018; this study.
MNA 360 (Ward Terrace)	Chinle Formation, Owl Rock Member, Apachean	AZ, Coconino	*Trilophosaurus buettneri* (questioned occurrence)	N/A	Kirby, 1991; Spielmann et al., 2008; Marsh et al., 2018

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PUEBLO PERIOD ARCHAEOFAUNA OF THE PETRIFIED FOREST: A BASELINE SYNTHESIS

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ABSTRACT – Petrified Forest National Park is widely known for its world-class paleontology, specifically its Late Triassic Period fossils, with park collections containing more than 80 holotype specimens (and counting). Far less familiar to most, however, is the park's impressive archaeological record, that spans much of the currently known spectrum of human presence in North America, or more than 13,000 years. Further, previous archaeological research in the park typically focused on inferences drawn from lithic and ceramic artifacts, along with rock imagery, while largely disregarding faunal remains from the very same sites. In an effort to begin correcting for these oversights, this study provides a rudimentary, first-time summary of the park's currently known Pueblo Period archaeofauna, and subsequently, a jumping off point for future, more rigorous archaeofaunal studies in the park and the surrounding area.

Keywords: archaeofauna, pre-Columbian archaeology, Pueblo Period, zooarchaeology

INTRODUCTION

Petrified Forest National Park's rich history of archaeological investigation has long favored the study of stone artifacts, ceramics and rock imagery over that of animal remains recovered from archaeological sites. In an effort to begin highlighting the importance of archaeofaunal or zooarchaeological studies to achieving a fuller understanding of the cultural history of the park and the surrounding area, this paper provides a basic introduction to fauna recovered from several of the park's more well documented Pueblo Period (700 to 1540 CE) sites.

LOCATION AND ENVIRONMENTAL SETTING

Petrified Forest National Park is located in northeastern Arizona, near the southern margin of the physiographic region known as the Colorado Plateau. Park lands range in elevation from approximately 1,600 m along the Puerco River, a substantial tributary of the Little Colorado River that divides the north and south halves of the park along its' northwest-trending course, to an elevation of about 1,900 m on the peak of Pilot Rock, located in the northwest corner of the park.

Marked by flat-topped mesas, highly stratified conical badlands and extensive dune fields, the area is primarily made up of semi-arid, short-grass prairie. In fact, the park protects "*one of the largest and best preserved areas of short-grass prairie in the entire country*" (Theuer and

Reed, 2012: 38). Despite being a landscape that tends to evoke emptiness, its native grasses, forbs and shrubs support a surprising diversity of life. Summer months, between June and September, are generally characterized by the North American Monsoon, the most important period of precipitation in the park. Local temperatures range from well below freezing in the winter to sustained temperatures around 100 degrees Fahrenheit in the summer.

The park's badland formations contain the well preserved, fossilized remains of plants and animals, organisms that were once part of a more equatorial ecosystem that characterized the area during the Late Triassic Period, some 215-220 million years ago. Importantly, the fossilized remains of trees, from which the park derives its name, provided the area's native human inhabitants with abundant raw material for the creation of their stone tools and building materials for some of their dwellings. Artifacts made from colorful and durable petrified wood are found in archaeological sites throughout the state of Arizona and beyond, with some dating back to as early as the Clovis Period, some 13,000 years ago.

BRIEF CULTURAL OVERVIEW

At the time of this report, there are approximately 1,300 archaeological sites (and counting), recorded within the park's administrative boundaries, with only about one quarter of the area having been subjected to formal archaeological inventory. Sites in the park include manifestations of the earliest known Paleoindian hunter and gatherer complexes, specifically Clovis and Folsom; artifacts representing the Archaic Period (8,000 BCE to 200 CE); evidence of the origins of maize-based agriculture and the earliest production of ceramics in the region, during the Basketmaker Period (500 BCE to 750 CE); to the beginnings of regional sedentism, represented by 5-500-room pueblo complexes during the Pueblo Period (700 to 1540 CE). The park's pre-Columbian site types include, but are not limited to, lithic and ceramic scatters, shrines, extensive rock imagery galleries, pithouse villages, and large pueblo complexes (Theuer and Reed, 2012). Although not directly relevant to the cultural periods dealt with in this discussion, the park also protects a number of important historic sites, including homesteads, a stagecoach stop, remnants of large Civilian Conservation Corps (CCC) era encampments, and sections of historic Route 66, among others.

PREVIOUS ARCHAEOLOGICAL DOCUMENTATION

The first archaeologist to travel through what is now Petrified Forest National Park, was Jesse Fewkes of the Smithsonian Institution, who visited and described Puerco Pueblo in 1896 (Fewkes, 1898). Some four years later, and just four years prior to the area becoming a National Monument, Smithsonian curator, Dr. Walter Hough and the Museum-Gates Expedition returned to the area (Hough, 1903). Hough and crew focused their efforts on documentation of Pueblo Period structures and associated features and collecting of artifacts from the Petrified

Forest and surrounding area. In 1917, some 16 years after the Museum-Gates Expedition, Leslie Spier of the American Museum of Natural History carried out fieldwork in the Wallace Tank area of the park (Spier, 1918). The following 50-60 years saw sporadic archaeological research conducted in the park, starting with Harry Mera in 1934, followed by Carl Jepson (1941), a regional Park Service archaeologist working out of Santa Fe, Erik Reed (1947), an archaeologist stationed at the park who conducted the first formal archaeological inventory of the park beginning in the 1930's, followed by Fred Wendorf (1953) in the late 1940's and early 1950's, and finally, Richard Woodbury (1954).

For much of the 20th century, the park did not have a formal "in-house" archaeology program. And though the park saw a number of archaeologists come and go over the past 20 years or so, it did not have its first permanent, full performance level professional archaeologist on staff until early 2022, more than 115 years after its establishment as a National Monument, and until then, none had specialized in zooarchaeology. The Western Archaeological Conservation Center (WACC), based in Tucson, Arizona provided the project-based staffing and subject matter expertise for most of the archaeological research conducted in the park from the 1970's through the 1990's. WACC-produced reports (Beckwith, 2007; Burton et al., 2007; Burton, 1990 and 1993; Corey, 2008; Jones, 1983, 1986 and 1987; Stewart, 1980; Wells, 1988 and 1989), continue to serve as cornerstones of the park's archaeological reference materials. The bulk of the archaeological work conducted in the park over the past couple of decades, however, could be described as reactive and compliance-driven, or student project-based in nature. While some of this work has resulted in important technical reports or master's theses, with a few notable exceptions (Hays-Gilpin, 2019; Schachner et al., 2016; Sinensky and Schachner 2019; Sinensky et al., 2021), very little has culminated in scholarly peer-reviewed publications.

ORIGIN AND SCOPE OF THE ASSEMBLAGES

Rather than focusing on a single site, or sites from a single developmental period, this study provides an introductory synthesis of fauna from multiple sites, over a period of approximately 600 years of human habitation in the park, beginning with the Pueblo II Period (900-1030 CE) and continuing up through to the Pueblo IV Period (1300-1540 CE). This approach was deemed necessary to compensate for a lack of archaeofaunal research conducted in the park over its 115+ year administrative history, resulting in data sets that are both few in number and relatively small in scale. Given the density of sites in the park and that its arid environment is favorable for bone preservation, this paucity of archaeofauna material available for analysis is likely the result of a combination of one or more of the following non-environmental factors: First, archaeological research in the area, particularly early 20th century efforts, strongly prioritized the collection and analysis of ceramic and lithic assemblages over faunal remains, often not collecting non-artifactual animal

bones at all (Gillespie, 1990; Lincoln, 1962). Historically, screening of recovered archaeological deposits (if they were screened at all), tended to employ the use of large-scale mesh sizes (1/4-inch or larger), which often fail to capture smaller taxa and highly fragmentary vertebrate remains. The thorough collection and curation of archaeofauna is generally driven by a principal investigator with faunal-focused research interests. If the investigator does not happen to possess that particular area of interest, then such items may not make their way from the field to a laboratory or permanent repository, and in turn, may never be included in a final report or manuscript. In some cases, only large, more identifiable bones were collected, with smaller more fragmentary remains simply being discarded, resulting in smaller and clearly biased samples (Gillespie, 1990). Lastly, from the mid-1990's to the present, park managers have largely discouraged excavation and subsurface sampling in the park, resulting in a lack of opportunities for faunal samples to be collected from archaeological contexts during this time.

The archaeofauna described here were recovered through full-scale excavation, targeted subsurface sampling and opportunistic surface collecting, at the following Pueblo Period sites: PEFO00245 (McCreery Pueblo); PEFO00552 (Puerco Pueblo); PEFO00134 (Saddle Horse Pueblo) and PEFO00491 (Wallace Tank). Due largely to the most extensive excavations having taken place at Puerco Pueblo (Gillespie, 1990), some 56% (number of identified specimens or NISP = 1,008), of the fauna reported here originated from that site, followed by McCreery Pueblo (Waters, 1993) at 23% (NISP = 416), Saddlehorse Pueblo at 19% (NISP = 344) and lastly, Wallace Tank at approximately 8% (NISP = 160). In total, this report describes a combined faunal assemblage composed of some 1,900 bones, representing 29 species, including 16 mammals, 9 birds and 4 reptiles or amphibians (Table 1). *Note:* Table 1 highlights those specimens identified to taxonomic order or beyond, and all numeric values represent the number of identified specimens (NISP).

Given that the fauna described here comes from multiple sites, representing a significant span of time, the sample size is not large. There also exists inherent sampling bias in the variety of strategies with which the combined assemblages were obtained. For these reasons, this basic summary is not one from which absolute conclusions should be drawn, but rather an important starting point for future, more extensive and detailed studies focused on the pre-Columbian archaeofauna of the Petrified Forest area.

METHODS

At the core of all zooarchaeology research is the accurate identification of vertebrate skeletal remains recovered from archaeological deposits. As these remains are often fragmentary and sometimes heavily deteriorated due to a number of long-term post-depositional environmental factors, this can be a challenging and time-consuming undertaking. With this in mind, when possible, specimens were identified to species level. All archaeofaunal bone not identified to the order level was defined as unidentified. All faunal specimens

TABLE 1. Taxonomic composition of Pueblo Period archaeofauna from Petrified Forest National Park

Common Name (Taxa)	McCreery Pueblo (PEFO00245)	Puerco Pueblo (PEFO00552)	Saddle Horse Pueblo (PEFO00134)	Wallace Tank Pueblo (PEFO00491)
American badger (*Taxidea taxus*)	-	3	-	4
bat Chiroptera	-	-	-	2
bighorn sheep (*Ovis canadensis*)	-	1	-	-
black-tailed jackrabbit (*Lepus californicus*)	96	88	74	57
bobcat (*Lynx rufus*)	-	2	-	-
Botta's pocket gopher (*Thomomys bottae*)	3	3	13	4
coyote (*Canis latrans*)	-	-	1	2
deer mouse (*Peromyscus* sp.)	-	1	-	-
desert cottontail (*Sylvilagus audubonii*)	95	282	54	44
Gunnison's prairie dog (*Cynomys gunnisoni*)	2	93	15	11
mule deer (*Odocoileus hemionus*)	-	2	-	-
Ord's kangaroo rat (*Dipodomys ordii*)	1	-	-	-
pronghorn (*Antilocapra americana*)	-	2	4	1
fox (red or gray) (*Vulpes* or *Urocyon*)	-	1	-	2
wolf/large dog (*Canis* sp.)	-	6	-	2
woodrat (*Neotoma* sp.)	2	6	-	7
Burrowing Owl (*Athene cunicularia*)	-	-	1	-
Golden Eagle (*Aquila chrysaetos*)	-	8	-	4
Mourning Dove (*Zenaida macroura*)	-	-	1	1

TABLE 1. (*continued*)

Common Name (Taxa)	McCreery Pueblo (PEFO00245)	Puerco Pueblo (PEFO00552)	Saddle Horse Pueblo (PEFO00134)	Wallace Tank Pueblo (PEFO00491)
Pied-Billed Grebe (*Podilymbus podiceps*)	-	1	-	-
Red-Tailed Hawk (*Buteo jamaicensis*)	-	-	-	1
Sandhill Crane (*Antigone canadensis*)	-	1	3	1
Scaled Quail (*Callipepla squamata*)	-	3	-	-
Turkey Vulture (*Cathartes aura*)	-	2	-	-
Turkey (*Meleagris gallopavo*)	3	-	2	3
gopher snake (*Pituophis catenifer*)	1	-	-	-
short-horned lizard (*Phrynosoma hernandesi*)	-	3	-	-
western painted turtle (cf. *Chrysemys picta bellii*)	-	1	-	11
spadefoot toad (*Spea* sp. / *Scaphiopus* sp.)	-	2	-	-

were tallied based on the number of identified specimens or NISP.

All skeletal identifications were achieved through direct one-to-one comparison with vertebrate reference materials from the Petrified Forest National Park Natural History Museum Collections, the Department of Ecology and Evolutionary Biology at the University of Arizona, loaned specimens from the University of Montana Philip L. Wright Zoological Museum (#L-2023-01), and private collections curated by the author and previous faunal analysts. Identifications were also aided by reference to Hoffmeister (1986) and various vertebrate osteology manuals (Broughton and Miller, 2016; Gilbert, 1990; Cohen and Serjeantson, 1996; Gilbert et al., 1996; Elbroch, 2006).

BRIEF SPECIES ACCOUNTS

MAMMALS

American badger (*Taxidea taxus*): Badgers are fossorial carnivorous members of the family Mustelidae, or weasel family, meaning they are adapted to digging and living primarily underground. The species prefers open grasslands with sandy loam soils easy for digging in and in the American Southwest, is commonly associated with the following plant communities: creosotebush (*Larrea tridentata*), junipers (*Juniperus* spp.), gambel oak (*Quercus gambelii*), willows (*Salix* spp.), cottonwoods (*Populus* spp.), ponderosa pine (*Pinus ponderosa*), grasses, and sagebrushes (*Artemisia* spp.) (Long and Killingley, 1983). The badger's diet is largely focused on subsurface-dwelling species, including gophers, ground squirrels, prairie dogs, moles and marmots, but also includes ground-nesting birds and snakes (Long and Killingley, 1983; Hoffmeister, 1986). Highly regarded in the Pueblo world, badgers are important as clan animals and in ritual (Tyler, 1975). Badger remains, specifically their canine teeth, claws and bacula, are known to serve as pre-Columbian burial items.

Bat (Chiroptera): There are at least six species (though likely more), currently known to inhabit the Petrified Forest area, including the pallid bat (*Antrozous pallidus*), Townsend's big-eared bat (*Corynorhinus townsendii*), California myotis (*Myotis californicus*), fringed myotis (*Myotis thysanodes*), Yuma myotis (*Myotis yumanensis*), and the canyon bat (*Parastrellus hesperus*). Which of these species is represented by the skeletal specimens found at Wallace Tank is unknown. Though bats are depicted in the park's pre-Columbian rock imagery, their potential importance as a past food source or use in ceremony is currently unknown.

Bighorn sheep (*Ovis canadensis*): The desert bighorn sheep (*O. c. nelsoni*) is one of three currently recognized subspecies of bighorn and occurs in the desert areas of southwestern North America and northwestern Mexico. Unlike other bighorn subspecies who receive the water they need through the vegetation they eat desert bighorn require regular access to surface water and although they are largely graminivorous, they also consume forbs and shrubs (Shackleton, 1985). Though not considered a resident of the park today, bighorn sheep are commonly depicted in the park's pre-Columbian rock imagery, as well as rock imagery of the surrounding area (McCreery and Malotki, 1994). In addition, park staff observed at least one bighorn ram that had ranged into the park in recent years (W. Parker pers. comm., 2023). Bighorn or "mountain sheep", were regularly hunted for meat (Tyler, 1975: 117), while their horn sheaths were fashioned into ladles and drinking vessels. Bighorn sheep are also commonly depicted in the park's rock imagery.

Black-tailed jackrabbit (*Lepus californicus*): This hare occupies mixed grass-shrublands of the western U.S. and Mexico, where they subsist on a variety of shrubs, grasses and forbs. Larger shrubs are required for hiding and nesting (Hoffmeister, 1986). Along with cottontails, hares represent the most common species recovered from sites in the park and are ubiquitous at archaeological sites throughout North America. They were regularly hunted by Native Americans "*for food, clothing, and to obtain raw material for the*

manufacture of bone tools…" (Hockett, 1991: 667). According to Tyler (1975: 132), rabbits (hares and cottontails), are so intertwined with the past subsistence strategies of peoples of the Southwest, that "*when the Pueblos speak of hunting, without mentioning some specific kind of game, they mean rabbit hunting*." Hares and rabbits were usually available regardless of the season or terrain and relatively easy to procure with a number of hunting and trapping strategies.

Bobcat (*Lynx rufus*): A medium-size felid, historically, the bobcat ranged from southern Canada, throughout the United States and into Mexico. Habitat loss significantly reduced the cat's territory, though they have successfully recolonized much of their former range in recent years. Lacking the oversized snowshoe-like paws of the Canada lynx (*Lynx canadensis*), deep snow seems to be a limiting factor in determining the species' range. They take a wide range of prey, from mice to deer, and their preferred habitat is highly varied (Hoffmeister, 1986). The reasons for the presence of bobcat in two of the sites remains unclear, though they may have been pursued for their hides or flesh.

Botta's pocket gopher (*Thomomys bottae*): A native of western North America, the Botta's pocket gopher inhabits a range of habitats, including scrubland and grasslands. The species is strictly herbivorous, with a particular focus on shoots and grasses. Their burrowing activities, which reach depths of 20 centimeters, directly affect local plant communities, and are considered vital to soil aeration in the region (Jones and Baxter, 2004). The oldest currently known fossil record of *T. bottae* is 103,000 years ago from southern California (Kurten and Anderson, 1980). Pocket gophers' presence in archaeological deposits is likely non-anthropogenic in nature.

Coyote (*Canis latrans*): A native Nearctic species found throughout Arizona, the coyote is most numerous in grasslands and open country (Bekoff, 1977). Despite nationwide efforts to eradicate coyotes, the species remains abundant. According to Hoffmeister (1986: 462), "when a coyote is hungry, it will eat almost anything", though they have a strong preference for small mammals, including rabbits, woodrats and mice, and are also known to eat a variety of vegetation. Coyotes pelts were sometimes used in ceremonial costumes and the pups occasionally eaten (Tyler, 1975). In Pueblo thought the coyote is important despite not being held in the high regard its cousin the wolf is and being considered a "*second-rate hunter*" (Tyler, 1975: 162).

Deer mouse (*Peromyscus* sp.): A very common and widespread species in the western part of North America, the deer mouse is perhaps best known as a carrier and vector of hantavirus. This mouse inhabits grasslands, scrublands and forest (King, 1968). They are a critical prey species for an array of predators, including raptors, small-to-medium carnivores and snakes. Their presence in the archaeological assemblage is likely due to non-anthropogenic factors.

Desert cottontail (*Sylvilagus audubonii*): One of three species of cottontail found in Arizona, the desert cottontail is found throughout much of the American west, though they are particularly common in the desert and semiarid grasslands of the southwest (Hoffmeister, 1986). They tend to occupy burrows abandoned by other mammals. Cottontails are usually comparable to jackrabbits as one of the most common prey species recovered

from southwest archaeological sites. A variety of grasses likely make up the bulk of their diet. They are a common prey item for most carnivores and larger species of snakes.

Gunnison's prairie dog (*Cynomys gunnisoni*): A species of the plains and desert grasslands, Gunnison's prairie dogs are found south of the Colorado River, with about three-quarters of the species population residing in Arizona and New Mexico. It is one of two species of prairie dogs and several small ground squirrels known from Arizona. Their diet consists of an array of grasses, forbs and sedges (Hoffmeister, 1986). They are integral to the health of sagebrush ecosystems. Prairie dog remains are commonly found in archaeological deposits through the American Southwest. They were regularly trapped for their meat, though some of their appearance in archaeological sites is surely the result of their use of the site following the conclusion of human habitation.

Fox (*Vulpes* or *Urocyon*): Red and gray foxes, though not numerous, are found throughout the state of Arizona. They prey primarily on rodents but are known to be quite opportunistic with their feeding habits (Hoffmeister, 1986). They are generally associated with wisdom and intelligence and are common clan and spirit animals. The primary role of the fox in Pueblo culture is the use of their pelts by ceremonial dancers (Tyler, 1975).

Mule deer (*Odocoileus virginianus*): A species of western North America, the mule deer is likely second only behind hares and rabbits as one of the most common species recovered from archaeological contexts in the western parts of the country. Deer were commonly hunted for their meat, marrow and sinew, while their bones and antlers were fashioned into a variety of tools. Deer hides were also made into garments and blankets.

Ord's kangaroo rat (*Dipodomys ordii*): This species of nocturnal kangaroo rat is found across the Plains and Great Basin of western North America, where they occur in sandy open areas of arid prairie, grasslands and scrublands (Garrison and Best, 1990). Their diet is focused on seeds of grasses and forbs, which they often store in large caches. Their presence in the archaeological record is likely due to their habit of burrowing into loose, unconsolidated soils, like those found in abandoned pueblo structural features.

Pronghorn (*Antilocapra americana*): The pronghorn is a species of open grasslands on the Great Plains and Great Basin. They are the only remaining species from the family Antilocapridae. They are known to seasonally migrate long distances. Forbs, shrubs and grasses makeup the bulk of their diet (O'Gara, 1978). The pronghorn is a regular player in various Native oral histories, and their remains are commonly found in archaeological deposits, as they were regularly hunted for food and for their hides (Bruchac, 1992). Their bones were also commonly fashioned into a variety of tools.

Wolf/large domestic dog (*Canis* sp.): The historic range of the Mexican species of gray wolf (*Canis lupus baileyi*) may very well have included the Petrified Forest Area, with molecular research suggesting that it did. Even if the Mexican wolf did not, other species of southwestern wolves (*C.l. mogollonensis and C.l. youngi*), were known to have inhabited much of the eastern half of the

state (Heffelfinger, 2017). DNA research shows that domestic dogs of Old World lineages accompanied late Pleistocene people to the North American continent (Leonard et al., 2002). Dogs were sometimes kept for their fur, flesh, companionship and protection, as well as for assistance in hunting. Wolves were considered gods in the Pueblo world, representing the East direction, they were "*gods for the hunter, for war and for curing*" (Tyler, 1975: 154).

Woodrat (*Neotoma* sp.): There are four species of *Neotoma* known to currently inhabit Petrified Forest National Park (Hoffmeister, 1986). Commonly referred to as "packrats" they are known to accumulate debris and food materials at their den sites. These middens are relatively common in the arid Great Basin and Southwest, and often contain hundreds or even thousands of years' worth of natural and cultural materials. Woodrats are common in archaeological deposits and were likely used as a periodic food source (Burton, 1990 and 1993).

BIRDS

Burrowing Owl (*Athene cunicularia*): A small-bodied owl with long legs, Burrowing Owls are residents of open country and grasslands. They are listed as an endangered species or species of special concern in some states, having declined in numbers due to large-scale cultivation of their prairie habitats and concerted efforts to exterminate prairie dogs, a species with which the owl has a symbiotic relationship (Alderfer, 2005). They regularly live in prairie dog colonies, making use of abandoned prairie dog burrows. In the Pueblo world, the Burrowing Owl is considered distinct from all other owls and sometimes beneficial to crops due to their regular predation of rodents. The Zuni refer to the Burrowing Owl as "*the priest of the prairie dogs*", in reference to their close ties to that species and their colonies (Tyler, 1979: 186).

Golden Eagle (*Aquila chrysaetos*): Found worldwide, and one of the largest raptors in North America, the Golden Eagle is an apex predator, hunting a wide array of prey, including large mammals, such as deer and domestic stock, and large birds, including Great Blue Herons and Turkey Vultures (Hardes in press). They are also known to feed on carrion with some regularity. Golden Eagles live in open and semi-open country across the Northern Hemisphere, preferring to avoid developed areas. Golden Eagles are central to Pueblo life and considered by the Hopi to be property, in much the same way as a horse might be owned (Fewkes, 1900). They were kept for their feathers and their bones modified and used in the making of bone whistles and a variety of other implements (Tyler, 1979; Burton, 1990: 210; Szuter, 1991; Strand and McKim, 1996; McKusick, 2001) (Figure 1).

Mourning Dove (*Zenaida macroura*): The most common and widespread dove in North America, Mourning Doves inhabit a diversity of ecological zones. They feed on the ground, while tending to avoid thick forest habitats (Alderfer, 2005). With their close relation to water in pueblo thought, doves are considered "*rain birds*", and their presence in archaeological deposits is most likelyrelated to use of their feathers in ceremonies (Tyler, 1979: 124).



FIGURE 1. Pueblo Period Golden Eagle femora exhibiting signatures of scoring and snapping, likely for the production of bone whistles used in hunting.

Pied-Billed Grebe (*Podilymbus podiceps*): A small, stocky swimming bird, this species of grebe is fairly common throughout much of North and South America. The species is apt to dive underwater rather than fly when threatened, and due to the placement of their feet far back on their bodies, they are unable to walk on land. They feed on a variety of prey items, including aquatic insects and snails, but tend to prefer crustaceans and small fish (Vuilleumier, 2020). If we assume the Grebe was seen as a variety of duck historically, its presence in an archaeological site is likely due to the importance of acquiring its feathers for ceremony, rather than it being used as a source of food (Tyler, 1979).

Red-Tailed Hawk (*Buteo jamaicensis*): This large, common hawk breeds throughout much of North America, from Alaska to Panama. They prefer open country, primarily preying on small mammals, though they are also known to eat snakes and scavenge carrion (Bent, 1961). Pueblo peoples use these birds and their feathers somewhat interchangeably with Golden Eagles in ceremony, even referring to them as the "*Red Eagle*" (Tyler, 1979: 53). Red-tailed Hawks are not uncommon in Pueblo Period sites of the Southwest and are in fact the most common hawk found in the extensive avian faunal assemblage from Chaco Canyon (Bishop, 2019).

Sandhill Crane (*Antigone canadensis*): Sandhill Cranes have one of the earliest known fossil records of any extant bird, with unequivocal specimens dating back 2.5 million years ago (Volz, 2003). Today, this large, long-legged, long-necked species is found on open freshwater wetlands throughout North America, where they enjoy a varied diet of seeds, berries, and an array of insects and small vertebrates (Tacha et al., 1992). Culturally, cranes are often related to the concept of guardianship and the universal importance of water (Tyler, 1979).

Scaled Quail (*Callipepla squamata*): Named for the appearance of its feathers, this species of quail is native to the American Southwest. They are a bird of open, low-growing grasslands, with a mix of shrubs and forbs, where they largely feed on seeds (Dabbert et al., 2009). Scaled Quail are preyed upon by a variety of mammals, birds and reptiles, as well as human hunters. In Pueblo cultures, Scaled Quail are considered taboo birds of the earth, and their feathers are not used in ceremony or prayer offerings (Tyler, 1979). They may have been consumed in precontact times.

Turkey Vulture (*Cathartes aura*): Ranging from southern Canada

throughout South America, Turkey Vultures are the most common vulture in the New World. They inhabit a wide array of habitats and subsist almost entirely off of carrion (Bent, 1961). Turkey Vultures may be preyed upon by Great Horned Owls, Golden Eagles, and other larger birds of prey. In the Pueblo world, Turkey Vultures are considered powerful priests and are closely related to cleansing and purification (Tyler, 1979). Their feathers are sometimes used in masks and on kachinas.

Turkey (*Meleagris gallopavo*): The largest of the native North American land fowl, Wild Turkeys are the ancestors to domestic turkey. They are highly adaptive birds that prefer hardwood forests with openings but will also inhabit marshes and swamps. Turkeys are omnivores that consume seeds and betties and also arthropods and small vertebrates (Eaton, 1992). Turkey domestication likely began in Mexico as early as 2,000 years ago but was certainly underway by about 700 CE. Though likely consumed on occasion, turkeys seem to have been kept primarily for their feathers which are central to the construction of prayer sticks (Tyler, 1979). Turkey bones are among the most common bones found in archaeological sites of the Southwest.

REPTILES / AMPHIBIANS

Gopher Snake (*Pituophis catenifer*): Gopher snakes are found throughout much of the western United States, with some 11 subspecies currently recognized. The species inhabits habitats from deserts and grasslands to woodlands and agricultural areas (Stebbins, 2003). They are non-venomous but known to mimic the defensive posturing of rattlesnakes. The gopher snake's appearance in archaeological deposits is likely the result of their use of the area following human habitation of the site.

Greater Short-Horned Lizard (*Phrynosoma hernandesi*): Endemic to the plains and mountains of western North America, this lizard is often referred to as a "horny toad" (Brennan and Holycross, 2006). Their diet is focused on ants though they will also consume a variety of other insects (Stebbins, 2003).

Western Painted Turtle (cf. *Chrysemys picta bellii*): The painted turtle inhabits slow-moving waters and is the most widespread native turtle of North America (Stebbins, 2003). Their native range includes only a small pocket of eastern Arizona. However, with their carapaces and plastrons being important pre-Columbian trade items throughout much of North America, those found in Petrified Forest sites may have originated from further afield.

Spadefoot Toad (*Spea* sp. or *Scaphiopus* sp.): Named for hind-foot projection that is spade-like, there are seven species of spadefoot toad found in North America. They are nocturnal and spend much of the dryer seasons lying dormant, buried underground (Stebbins, 2003). The presence of their remains in an archaeological site is most likely non-anthropogenic in nature.

IMPORTANCE OF ARCHAEOFAUNAL STUDIES

The importance of faunal remains to archaeological studies is perhaps best summarized by the late icon of

American archaeology, Lewis Binford: "*It may come as a surprise to some that most of the behavioral ideas regarding our ancient past are dependent on the interpretation of faunal remains…not as most textbooks would lead one to believe, stone tools. In fact, in all the arguments I have reviewed regarding the behavior of ancient man, almost all are dependent on inferences drawn from faunal facts…*" (Binford, 1981: 3). Analysis of animal bone from archaeological sites can help to answer a seemingly endless series of research questions. And, unlike many other archaeological remains, whose identities and usage are often left to individual interpretation, with some effort, more complete vertebrate skeletal remains can generally be identified to the individual skeletal element and often times assigned to the particular genus or species from which they derived.

The study of archaeofauna and their various taphonomic signatures can illuminate predator-prey relationships, dietary spectrum and preferences, hunting practices, butchering and processing methods, cooking practices, past environmental/ecological conditions, extinction events, shifts in biodiversity, human-induced environmental impacts, individual social status, various aspects of domestication, long-distance trade, spiritual and ceremonial importance, and countless other research questions. Simply put, these are questions that other archaeological remains and lines of archaeological evidence are generally not capable of answering.

Employing *applied* zooarchaeology, through understanding the park's archaeofauna, can directly assist park resource managers with directives aimed at maintaining and/or reestablishing historical species breadth and numbers on their administered lands. This notion is supported by Lyman and Cannon's (2004: xvi) argument that, "*with its unique perspective on the time depth of ecosystems and biota, and their evolution and history, zooarchaeological research can be used to help ensure that the best-informed wildlife management decisions are made and that well-informed efforts in conservation biology are undertaken*".

DISCUSSION

The taxa identified in archaeofaunal assemblages from sites in Petrified Forest National Park can provide insight into a variety of past environmental conditions. Some of the avifauna described here for example, point to the potential of a wetter environment in the Petrified Forest than the one we see in the present day. Though given the highly migratory lives of some avian species, their presence may not point to particular conditions or specific habitats in the immediate area. Presumably, even if ephemeral in nature, some degree of preferred habitat existed for certain species to choose to stop in the area during their seasonal migrations. Sandhill Cranes for example, prefer marshy habitats with standing water, while the Pied-billed Grebe inhabits ponds and marshes, specifically those with thick aquatic vegetation. With a diet consisting mostly of crustaceans and small fish, the Pied-billed Grebe must live near reliable, permanent bodies of water. With the exception of a handful of highly ephemeral playas, habitat types

such as these do not currently exist in the park.

The remains of turtles of unknown species, but that compare favorably (cf.) to *Chrysemys picta bellii*, are reported from two of the four sites included in this study (Table 1). Further analysis is required to verify a taxonomic assignment for these remains, as they are represented entirely by fragmentary pieces of carapace and/or plastron (top and bottom portions of the shell). Arizona has eight native species of turtles or tortoises, including aquatic, semi-aquatic and terrestrial species. The painted turtle represents the geographically closest known species to the research area, with populations in the St. Johns area of southern Apache County, approximately 60 kilometers (37 mi.) to the southeast. Regardless of their species, turtle shells were known to be traded throughout the precontact desert Southwest and beyond, a fact that may account for their presence in the park's archaeological record.

The Burrowing Owl, Pied-billed Grebe, Sandhill Crane and Turkey Vulture would have been seasonal migrants to the area and absent during the colder months. The Golden Eagle, Mourning Dove, Red-tailed Hawk and Scaled Quail, on the other hand, likely would have inhabited the research area year-round (Bridges, 2018). It is unclear if the Turkey remains represent local wild birds, a kept domesticated variety, or a combination of both.

A number of the genera and species highlighted here, including the Pied-billed Grebe, Sandhill Crane, Turkey, bighorn sheep and turtle, are either no longer residents (seasonal or year-round) of the park or would now be considered rare or infrequent visitors to the area (Chesser, 2018; Hoffmeister, 1986; Van Riper and Lamow, 2006; Vuilleumier, 2020). In some cases, they may never have been residents, but simply had their remains traded or otherwise transported to the area. This may be the result of a change in availability of and access to water on the landscape through time, which is less common today than it was historically. Playas now hold water for shorter periods of time and do not fill to the extent they once did, springs no longer recharge to past levels or have entirely dried up, and the Puerco River, and its tributaries are completely dry for an appreciable portion of the year. This relative aridity leads to the presence of few highly water-dependent species such as waterfowl and turtles who are highly dependent on water for feeding, breeding and safety, and fewer large mammals that must have regular access to sources of water for drinking. The dryer climate also directly affects the makeup and diversity of available plant life, which in turn influences the ability of herbivorous species to inhabit the park.

The current presence of the Gunnison's prairie dog, a native to the area, has been enhanced through recent reintroduction efforts by park staff (Schneider, 2022). Severe decreases in the number of prairie dogs in the park due to zoonotic disease and twentieth century extermination efforts, led directly to the loss of the Black-footed ferret (*Mustela nigripes*), a species that survives solely through its symbiotic relationship with the prairie dog, their number one prey species. Black-footed ferrets depend on prairie dogs for some 90% of their diet and also utilize abandoned prairie dog burrows for

shelter and raising of their young (Owen et al., 2000).

CONCLUSIONS

Some 120 years ago, Walter Hough, assistant curator of ethnology at the Smithsonian National Museum of Natural History (and the first individual to conduct formal archaeological investigations in what is now Petrified Forest National Park), recognized the importance of faunal analysis to achieving a more holistic approach to archaeological research in the area, when he stated: "*It is hoped that in future excavations in the Southwest, all bones of animals be carefully collected for the sake of aid they afford to a fuller understanding of the life of the pueblo dwellers*" (Hough, 1903: 857). The classic phrase "*better late than never*" comes to mind as current archaeologists now strive to reach this goal during the planning and execution of all archaeological investigations carried out in the park.

Despite the relatively small and incomplete nature of the faunal assemblages discussed here, they nevertheless afford an important initial glimpse into the breadth and diversity of fauna encountered and utilized by Pueblo Period agriculturalists of the area. Far more extensive and detailed studies centered on the analysis and interpretation of Petrified Forest National Park archaeofauna assemblages are essential to answering the many questions pertaining to Puebloan habitation of the greater Petrified Forest area, questions that can only be addressed through the detailed recovery and analysis of these unique archaeological remains.

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JAVELINA (*DICOTTYLES TAJACU*) RANGE EXTENSION INDICATED BY NEW SIGHTINGS IN PETRIFIED FOREST NATIONAL PARK

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ABSTRACT — Javelina sightings in Petrified Forest National Park (PEFO) are increasing after the first recorded observation in 2018. The current seven recorded sightings detailed in this report are just the latest observations in an apparent northward expansion of this species. While not surprising due to unrecorded sightings from Arizona Game and Fish Department (AZGFD) and increased surveillance, javelina have not been officially documented in this region before. Habitat change due to overgrazing and drought as well as warmer temperatures may play a factor in this expansion.

Keywords: Javelina, Range Extension, National Park Service, Petrified Forest National Park

INTRODUCTION

Javelina (*Dicottyles tajacu,* formerly *Pecari tajacu*, formerly *Sus tajacu* Linnaeus 1758), also known as collared peccary or musk hog is the widest ranging of three extant species in the family Tayassuidae, ranging from Northern Argentina to the Southwest United States. They can tolerate a wide range of habitat from desert to tropical and subtropical grasslands, savannas, and tropical and subtropical dry broadleaf forests. While absent from many stories and accounts of travelers, hunters, and pioneers from the 1800s that included other common animals of the area (Sowls 1997), they have become increasingly common in accounts of the Southwestern United States since then (Manaster 2006). There is little to no historical evidence (remains or images) from archeological sites in Arizona (Davis 1982 qtd. in Swols 1997). Historically, peccaries have had large range movements. Peccaries moved to North America from Asia about 36 MYA (million years ago). Fossils of several extinct species of peccary have been found in North America (Wyoming, Nebraska, South Dakota: Prothero, D. 2009). They appear to have moved to South America during the Great American Biotic Interchange (2.7 MYA) and then gone extinct in North America when humans colonized the continent (Wilson and Hill 2020). Since the 1700s, the range of the javelina is in flux.

Populations have decreased and then increased in Texas and increased in Arizona (Sowls 1997). A northward range expansion has been observed for javelina in Arizona. Arizona Game and Fish Department (AZGFD) states that javelina have been in Northern Arizona in very low densities for approximately 20 years (unpublished data personnel communications). However, this study discovered no published observations of javelina north of the Mogollon Rim in Arizona. Albert et al. (2004) published observations from the Zuni Indian Reservation in New Mexico, 40 miles east of the observations in Petrified Forest National Park (PEFO). One of

these observations date back as far as 1979 but most are from the 1990's or more recent. Recent sightings in PEFO are the first recorded sightings of this species in the park and this paper is intended to provide a published record.

MATERIALS AND METHODS

For historic observations in PEFO, the PEFO wildlife observation database, wildlife observation cards, the park photo collection, and iNaturalist (www.inaturalist.org) posts were examined. Conversations were held with staff from the Arizona Game and Fish Department (AZGFD) office in Flagstaff, Arizona, where we requested additional detailed range information but did not receive any. Specific locality information is available to qualified researchers from the park ecology program.

RESULTS

The methodology yielded seven individual observations of javelina in PEFO.

1) 26 February 2018: A volunteer working in the park saw one javelina "¾ miles" east of main park road while hiking in the Puerco River at 1500 hours. They were "30-40 yards" apart and had photos (not available to this study but confirmed by park staff at the time). (No temperature was recorded)

2) 25 July 2018: One javelina was captured on a game camera at McCray Well at 0509 hours, temperature was 13°C. 5 photos were recovered.

3) 31 December 2021: At McCray Well, between 2018 to 2025 hours, a game camera took 83 photos of at least four distinct javelina including two young of the year, temperature was 0°C.

4) 2 January 2022: At McCray Well, at 1548 to 1551 hours, a game camera took 57 photos of four distinct javelina with two young of the year. Ground had ~2.5-5cm of snow cover and temperature was 8°C.

5) 30 September 2023: At McCray Well, a game camera captured two photos of one javelina at 1853 hours (approximately 50 minutes after sunset). Temperature was 23°C.

6) 10 November 2023: Two visits to McCray Well at 1218 to 12:22 hours (12 photos/videos) and 1553 hours (4 photos/videos). Four total distinct javelina were observed at one time including two adults and two young of the year, temperature was 17°C and 13°C.

7) 11 November 2023: Two visits to McCray Well at 1025 hours (7 photos/videos) and 1520 hours (11 photos/videos) there were four distinct javelina, two adults and two young of the year were observed with temperatures of 21°C and 16°C.

DISCUSSION

Javelina have specific physiological requirements that could make northern range expansion challenging. Javelina anatomy nor physiology are adapted to extreme heat or cold and must rely on behavioral adaptations to thermoregulate. Core body temperatures range from 37.9°C to 38.5°C and increase up to 0.5°C throughout the day (Phelps,

1971). Even though javelina have sweat glands they have minimal water loss through the skin (Sokolov, 1982). With minimal water loss, evaporative cooling is not effective. However, it does help javelina maintain water balance in dry climates. Instead of sweating, javelina rely on panting to keep cool. (Phelps, 1971). Zervanos and Hadley (1973) found their pelage was a very poor insulator. However, they found in summer the dark tips of the bristles would commonly break off revealing white bristles underneath. This less dense coat and lighter color resulted in more heat reflection in summer. The darker coat in winter absorbed more solar radiation, increasing body temperature. They also found an increase in metabolic rate was needed to maintain core body temperatures, thus requiring higher food consumption. However, these physiological adaptations alone cannot account for the many environments javelina currently utilize (Zervanos and Hadley 1973). Adapted behaviors include social huddling for warmth, utilizing heavy thickets for insulation, being active in the heat of the day, and using landscape variables such as move between hot or colder microhabitats as needed. These microhabitats include features like shade or caves to stay cool and basking in open sunny areas to stay warm (Swols, 1997).

Most of the important food sources described by Swols (1997) do not occur in PEFO. The two major exceptions are prickly pear (*Opuntia* spp.) and cholla (*Cylindropuntia* spp.) cactus, which constitute a major food source, especially in winter. While not uncommon, neither cactus species occur in high densities in the park. Javelina consume large amounts of roots, tubers, bulbs, and rhizomes (Knipe, 1957 qtd. in Swols, 1997). Day (1985 qtd. in Swols, 1997) found red brome (*Bromus rubens*) to be one of the six most consumed plants. The wide range of habitat javelina are found in attests to their adaptability. Although PEFO's grasslands may be new to javelina, it does contain many similar food species as other javelina habitat. Additional studies are needed to parse out which local species are being utilized.

Factors. In the past several years there has been a clear uptick in javelina sightings in PEFO. This is likely due to several factors, including: 1) range expansion, 2) park expansion, 3) increased surveillance.

Range expansion: Javelina range has been in flux since the earliest European settlers arrived in the Southwest. In Texas, they have shifted south, but in New Mexico and Arizona they have expanded northward (Manaster, 2006). Starting in the late 1990s, sightings have occurred at Flagstaff, Arizona (unpublished data AZGFD), surprisingly overcoming the Mogollon Rim obstacle and the cold winters that come with elevation gain. Javelina can now be found as far north as the South Rim of the Grand Canyon while in New Mexico they can be found northwards to Albuquerque. Presently, the iNaturalist website shows wild javelina sightings in an arc ranging in the northwest from the South Rim of the Grand Canyon, southward to Flagstaff, along the Mogollon Rim to Show Low in Arizona, and then curving northeast to Albuquerque, New Mexico (Figure 1). The PEFO sightings occur in approximately the center of this arc. AZGFD (unpublished data) indicated

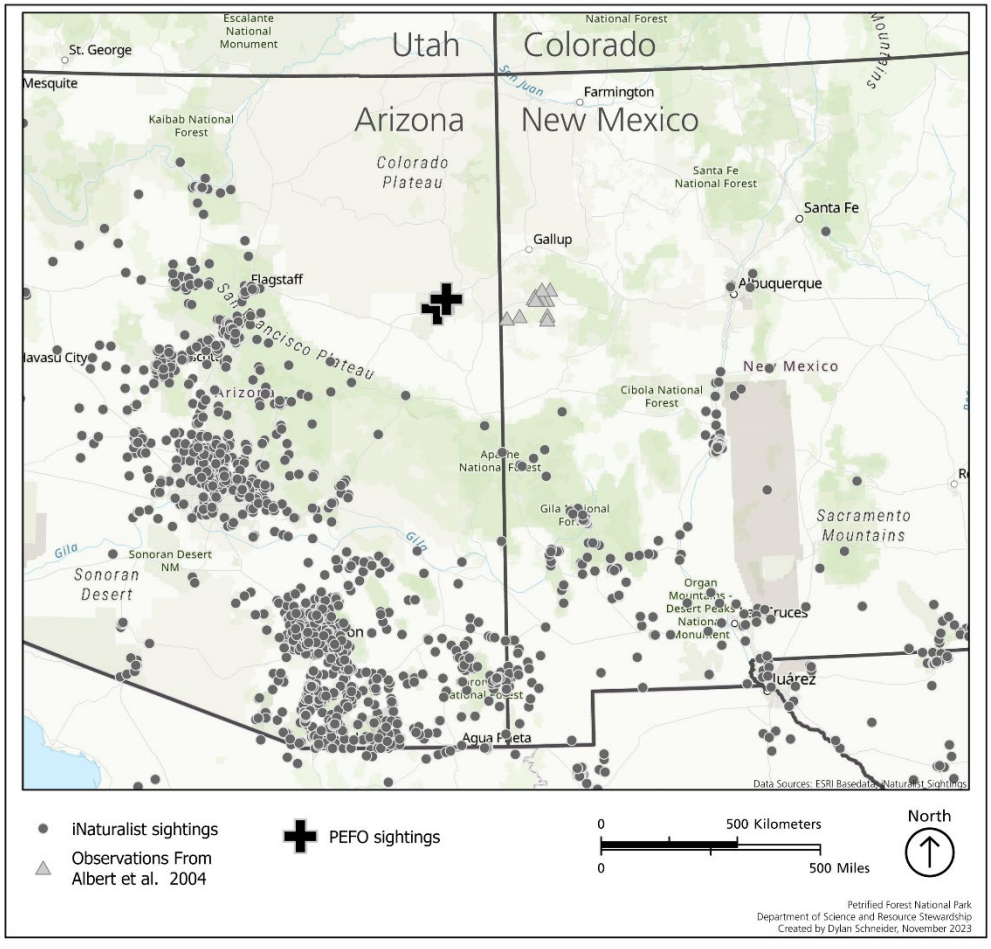


FIGURE 1: Map of javelina sightings in the four-corners region of the Southwestern United States. Sightings are from observations published in Albert et al. 2004 and the iNaturalist website that allows the public to upload sightings. All iNaturalist sightings have been verified by more than the original observer. While using public observations has its flaws of misidentification and mis-marked locations, for the purpose of this paper, species identification has been verified by numerous sources. Also, javelinas are a distinct looking species making confusion with a local species unlikely. "Obscured" locations still show up within 10km of the original sighting, while handpicked locations can be off significantly, the number of sightings overcome some of these issues as well.

they have observed javelina in very low density between the Mogollon Rim and the Navajo Nation since around 2000, and that the Navajo Nation appears to be the reported northern limit at this time.

Park expansion: In 2011, PEFO acquired ~40,000 acres on the east side of the park, checkerboarded with another ~35,000 acres of state land. This expanded terrain included approximately 19 km of the Rio Puerco riparian area. Numerous stock tanks and wells were also included in the purchase. The increase from ~2 km to ~21km of

riparian habitat significantly raise the odds of encompassing javelina habitat. Indeed, this is observed in six of the seven sightings occurring at a water well located on the new property.

Increased surveillance: An increase in park personnel, combined with increased surveillance of the new park lands has increased the detection rate of catching rarely occurring species. Most observations reported here are from remote game cameras at a single watering hole. Surveillance efforts have been biased on targeting probable high use areas for all wildlife, rather than utilizing a systematic survey approach to the riparian areas. Interestingly a few game cameras set up in the Rio Puerco bridge area, close to the first reported sighting, have not detected anymore additional observations.

To date all javelina observations in PEFO occur in, or along, the riparian corridor of the Rio Puerco. This is understandable, due to thermodynamic and food requirements specific to javelina. Herd size appears small, with a minimum of four individuals observed at once, but this could be a result of the limited food resources or low caloric value of dispersed food sources. However, occurrences of young javelina in the observed groups suggests local breeding is occurring and that sightings are not just a representative of dispersing animals.

CONCLUSIONS

The PEFO sightings of javelina are the most recent of many documented range expansions northward within Arizona but are an important one to document. These sightings may indicate javelina movement out of the conifer forests of the Mogollon Rim and into the desert grasslands and dry wash valleys of Northern Arizona.

Javelina expansion has not been studied in detail, so the causation of such expansion is presently not understood. Several reasons are offered here: reduced competition from other peccary species, habitat creation due to local overgrazing of grasslands producing a more favorable habitat of scrub and cactus, a reduction in predators, and climate change reducing the physiological demand in winter as well as creating more favorable habitat, including food species. However, a combination of several factors may have contributed to their spread.

RECOMMENDATIONS

Recorded javelina sightings are increasing in recent years, especially within PEFO. The authors recommend starting a formalized surveillance program especially along the Rio Puerco and

surrounding riparian habitat. Develop projects to determine specifics such as home range size, herd size, and forage requirements for Northern Arizona. Continue monitoring habitats to the north of PEFO to follow any further northward expansion.

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DESCRIPTION OF A NEW UPPER TRIASSIC FOSSIL LUNGFISH (SARCOPTERYGII:DIPNOI) LOCALITY FROM THE GARITA CREEK FORMATION, EAST-CENTRAL NEW MEXICO, WITH A REEVALUATION OF LATE TRIASSIC LUNGFISH DIVERSITY IN THE AMERICAN SOUTHWEST

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ABSTRACT — Mesozoic lungfish fossils ordinarily consist of isolated tooth plates. Many tooth plates, typically assigned to *Arganodus*, are known from the Upper Triassic of the American Southwest. The new Homestead Site at Garita Creek is the most extensive vertebrate assemblage described from the Garita Creek Formation in east-central New Mexico. It has yielded enough new lungfish fossils (18 nearly complete-complete and 43 fragmentary tooth plates) to qualify as the second-richest Upper Triassic lungfish site in North America. We measured the tooth plates of Homestead and several others from the Chinle, identifying multiple tooth plate morphotypes, including ones with only 4–5 ridges that fall outside the diagnosis of *Arganodus*, suggesting that the Homestead assemblage preserves at least two taxa. Reevaluating 32 previously published PEFO tooth plates further supports the presence of two morphologies: a more common morph we assign to *Arganodus* sp., and a second morph that we assign to cf. *Ptychoceratodus*. *Ptychoceratodus* has a limited presence in North American strata, but is known from the Late Triassic of Greenland. A ptychoceratodontid in the Upper Triassic of western North America greatly increases their geographic range during the Triassic, and shows that they coexisted with *Arganodus* on at least three modern continents.

Keywords: Lungfish, *Arganodus*, *Ptychoceratodus*, Tooth Plate, Late Triassic, Chinle.

INTRODUCTION

The Upper Triassic strata of the Colorado Plateau yield world-famous assemblages of vertebrate fossils, especially of archosaurian reptiles, including some of North America's oldest dinosaurs (Long and Murry, 1995; Heckert et al., 2005; Parker, 2005, 2006; Nesbitt et al., 2007; Marsh and Parker, 2020). These same strata also yield fossils of fishes, including dipnoans (Huber et al., 1993; Milner et al., 2006; Gibson, 2016; Kligman et al., 2017), but these are often more fragmentary and have historically not been afforded the same attention. While there are some assemblages of articulated fish from Upper Triassic strata in the American Southwest (Schaeffer, 1967; Johnson et al., 2002; Gibson, 2016, 2018), most fossil osteichthyans and chondrichthyans are found more incidentally, often as isolated and/or fragmentary fossils in microvertebrate assemblages (Murry, 1986

1989; Heckert, 2004; Kligman et al., 2017). Sarcopterygian fish, including coelacanths and lungfish, however, are sometimes recovered from larger, isolated fossils (Hunt, 1997; Milner et al., 2006). To date, Murry (1989) is the most recent author to document lungfish diversity and taxonomy from these strata, and in his analysis described a prolific site, the "lungfish locality" in Petrified Forest National Park (PEFO) that yielded 30 tooth plates, two vomerine teeth, and an additional 80 tooth plate fragments. While Polcyn et al. (2002) preliminarily described a site near Stinking Springs, Arizona, southeast of PEFO, that they said yielded approximately 700 toothplates, they did not illustrate or describe these fossils, thus Murry (1989) remains the most recent taxonomic treatment.

In this paper we describe a new assemblage of lungfish tooth plates from a site in east-central New Mexico and compare them to other lungfish tooth plates of similar age across the Colorado Plateau in New Mexico, Arizona, and Utah, including previously published specimens from the Petrified Forest National Park (PEFO), to expand upon the known diversity of Late Triassic lungfish in North America (Fig. 1). The new assemblage consists of 26 relatively complete tooth plates (Fig. 4) gathered from the Homestead Site at Garita Creek, located in the Garita Creek Formation of eastern New Mexico, as well as previously studied specimens from the Bluewater Creek Formation in New Mexico, Blue Mesa Member in Arizona, and Petrified Forest ("Painted Desert") Member in Utah (Fig. 1). As of now, Homestead is a largely unpublished assemblage, so we provide a brief summary of the stratigraphy, sedimentology, and taphonomy of the site, as the majority of the fossils used for this project were collected from it.

Upper Triassic lungfish from the American Southwest have long been considered to represent a single taxon, *Arganodus*, sometimes referred to the species *Arganodus dorotheae* (Murry, 1989; Hunt et al., 1989; Milner et al., 2006), which apparently replaced the Middle Permian sagenodontid taxa *Sagenodus* and gnathorhizid taxa *Gnathorhiza* (Pardo et al., 2010). The Ceratodontiformes were the only group of dipnoans that remained globally post-PTB (Kemp et al., 2017). Their diversity in the Mesozoic is still relatively poorly understood due to their mostly incidental occurrences worldwide as isolated tooth plates.

As with most vertebrates, cranial material is most taxonomically diagnostic in dipnoans down to the species level due to the unique structuring and fusion of bones in the calvarium (Kemp, 1998). However, reduced ossification of the skeleton in post-Paleozoic taxa has resulted in a near-total lack of fossil bone in the record of Mesozoic and Cenozoic lungfish (Cavin et al., 2007). Lungfish do, however, possess a dentition that is readily diagnostic to the genus level, and thus their tooth plates can be used as valid taxonomic indicators when identifying genera in the absence of cranial material (Kemp, 1998), though allometry, ontogenetic change, positional variation, and wear facets limit these assignments. Consequently, many species have been based on characters that may change over the course of ontogeny (Murry, 1989). Martin (1982) proposed a handful of phylogenetically informative characteristics for differentiating Mesozoic ceratodontoids, generally based solely on tooth plates, and specifically for identifying the four following families: Ceratodontidae, Ptychoceratodontidae, Arganodontidae, and the still extant Neoceratodontidae, all of which occur in Mesozoic strata.

In general, these diagnoses are based on the number, size, and shape of the ridges and intervening furrows (Fig. 2A–D, G).

Lungfish tooth plates form during development as rows of individual cusps that fuse together into a radiating, fan-shaped occlusal surface (Kemp, 2002). These plates continuously grow instead of undergoing continuous replacement as in most other fish (Kemp, 2002). Individual species may have uniquely shaped tooth plates, but features of these plates may change shape as the animal matures (Skrzycki, 2015). Although some morphological features change as a result of growth and wear, others remain unmodified (Kemp, 2005; Skrzycki, 2015). According to Skrzycki (2015), unmodified features include: the general shape of the tooth plates, position of palatal plates in relation to each other, the pattern of ridges (parallel or anterior/medial radiation), the shape of upper and lower symphyses, the morphology of the enamel to bone junction, the position of pterygopalatine ascending process, and form of prearticular sulcus. The origin of ridges, shape of first ridge crest, and relative length of first ridge to the lingual margin (ratio of anchor points BC_1/BC_p, Fig. 2E–F) may change slightly (Skrzycki, 2015). The most changeable characters are the size of the tooth plate, distinctiveness of inner angle tip (anchor points ABC, Fig. 2E-F), sharpness of ridges, morphology of the last ridge, the depth of furrows, the extent of the occlusal surface, the presence of denticles, and location of occlusal pits, most of which are clearly affected by wear facets (Skrzycki, 2015). Therefore, while tooth plates are useful for taxonomic identification, there are limitations.

While Kemp (1997) was skeptical of the taxonomic value for biometric measurements of isolated tooth plates, specifically the methods established by Vorob'yeva and Minikh (1968), there is no rigorous test of her hypothesis in the literature regarding these measurements offering insignificant taxonomic information. That is, neither Kemp (1997) nor other dipnoan workers have demonstrated that lungfish tooth plates, especially those of Triassic age sediments, yield ambiguous or spurious taxonomic assignments. Skrzycki (2015) has stated that sole application of these biometric plate measurements does not help to discriminate between morphologically similar species, which is why it can be used as independent support of morphological comparisons. Many have successfully used tooth plate characters in addition to biometric measurements to generate taxonomic hypotheses in the absence of cranial material (e.g., Martin et al., 1981; Martin, 1982; Murry, 1989; Milner and Kirkland, 2006; Soto and Perea, 2010; Skrzycki, 2015; Frederickson and Cifelli, 2017; Skrzycki et al., 2018), so we rely on those studies extensively here.

MATERIALS AND METHODS

The motivation for this study stems from the "Homestead Site at Garita Creek Project," or Homestead site, of east-central New Mexico (Fig. 1, 3). This is a collaborative effort undertaken by personnel from ASU, the Lauer Foundation, VT, and NHMUK. The land and fossil assemblage are property of the Lauer Foundation and thus the specimens described here are available to qualified researchers per the earlier curation statement. A majority of Homestead fossils were collected by Larry and Betty Martin, with more recent samples collected by personnel from ASU, VT, NHMUK, and Lauer Foundation. The initial collection from

the Martins is referred to as the "picked bags," which are minimally sorted but contain most of the more complete specimens and/or material they considered more diagnostic. The rest of their collection is termed the "concentrate," which includes all the material that did not make it into the picked bags. Of the 18 tooth plates found at Homestead (Fig. 1, 4A–R); 16 were recovered from the picked bags, another was found in the concentrate, and the last one was surface collected from the "wash" area in 2021. An additional 43 plate fragments were also recovered from Homestead.

The second and third localities, from the Bluewater Creek Formation of west-central New Mexico and Blue Mesa Member of east-central Arizona, have yielded two and three tooth plates respectively (Fig. 1, 4S–W). These sites are designated as NMMNH localities L-3380 and L-6818. Additionally, a fourth locality, in the Petrified Forest Member (Painted Desert equivalent) of southeastern Utah, yielded three tooth plates (Fig. 1, 4X–Z). This is the Four Aces mine locality of Parrish (1999), and is designated as UCM-97074. The tooth plates of these three localities were loaned to ASU for use in this project by NMMNH and UCM. Of the 32 tooth plates within Murry's (1989) PEFO assemblage (Fig. 1), none of the fossils used within his original study were originally available for this project, as they remained in his possession. Only the figure and data tables provided in the original publication were utilized in this current study, although we have subsequently been in touch with personnel at PEFO to verify some observations of fossils that have since been returned to PEFO.

Terminology of the morphological features on individual tooth plates (Fig. 2A–D) typically follows Kemp (2002), with some revisions for this study following Churcher et al. (2006). Additionally, the point formed by the mesial and lingual margins of tooth plates (anchor point B, Fig. 2E–F) is referred to by many names in publication, and is often considered synonymous with the angle that it forms (anchor points ABC, Fig. 2E–F). Some examples of these names include "inner angle" (e.g., Kemp, 1996; Cavin et al., 2007; Skrzycki, 2015), "angulus internus" (e.g., Murry, 1989), "mediolingual junction" (e.g., Vorob'yeva and Minikh, 1968; Kemp, 1996; Skrzycki, 2015; Pawlak, 2020), or "mesiointernal angle" (e.g., Churcher et al., 2006). While any of these terms are interchangeable, we prefer the name "mesiolingual corner," following Frederickson and Cifelli (2017), as it most accurately represents the connection between the mesial and lingual margins (Fig. 2A–D). Ridges normally radiate from this corner, but this is not always the case for some species (Churcher et al., 2006). When referring specifically to angle ABC, we use the distinction "angle" rather than "corner," following Soto and Perea (2010).

Here we analyze the morphology of each tooth plate, noting any differences that may indicate separate taxa. We follow the list of characters compiled by Skrzycki (2015). Here we emphasize the number of ridges present, as it is the character that most readily distinguishes between genera when fossil bone is not available. All fossils used in this project were photographed in occlusal view using a Keyence VHX 3D microscope. The length and width (in mm) of each tooth plate were measured using the ImageJ.JS web application v. 0.5.7 (Ouyang, 2024). Each tooth plate image was subsequently cropped and edited using Adobe Photoshop, with 15 having been tentatively reconstructed in Adobe Illustrator due to fractures or strong wear facets (proposed

reconstructions shown by dotted lines, Fig. 4).

Institutional Abbreviations — **ASU**, Appalachian State University, Boone, NC, U.S.A.; **LF**, the Lauer Foundation for Paleontology, Science and Education, Wheaton, IL, U.S.A.; **NHMUK**, the Natural History Museum, London, England, United Kingdom; **NMMNH**, New Mexico Museum of Natural History and Science, Albuquerque, NM, U.S.A.; **PEFO**, Petrified Forest National Park, AZ, U.S.A.; **PFV**, Petrified Forest National Park fossil vertebrate locality; **UCM**, University of Colorado Museum of Natural History, Boulder, CO U.S.A.; **UMMP**, University of Michigan Museum of Paleontology, Ann Arbor, MI, U.S.A.; **VT**, Virginia Tech, Blacksburg, VA, U.S.A.

Curation Statement — The Lauer Foundation provides the scientific community and other museums with permanent access to their own curated fossil collection for the purposes of exhibition, study and education. They guarantee public access to type and figured specimens, as well as specimens listed or cited in publications together with other scientifically important specimens.

PREVIOUS STUDIES

The first publication of Upper Triassic lungfish tooth plates now recognized as *Arganodus* from Upper Triassic strata in North America was by Case (1921), who described a singular tooth plate from the UMMP vertebrate paleontology collection ("geological collection" at the time of publication). This tooth plate, UMMP-7324, was collected from Upper Triassic beds of the Dockum Group in Crosby County, Texas (Case, 1921). The plate was assigned as the holotype for *Ceratodus dorotheae*, the first occurrence of "*Ceratodus*" from the Triassic of North America (Case, 1921). An additional tooth plate, UMMP-9634, from Upper Triassic beds of the Dockum Group at Walker's Tank, Crosby County, Texas, would later be described by Warthin (1928) as the holotype for *Ceratodus crosbiensis*, which was the second Triassic occurrence of "*Ceratodus*" in North America. However, "*C*." *dorotheae* and other subsequently collected specimens would later be reassigned to a separate genus, *Arganodus*, as *Arganodus dorotheae* (Martin, 1982). Martin (1982) simultaneously established the new family, Arganodontidae (Martin 1982), and this taxonomy has generally been followed by other Triassic workers in the American Southwest (Murry, 1986, 1989; Huber et al., 1993; Milner et al., 2006). Murry (1986) considered Warthin's (1928) "*C*." *crosbiensis* a junior subjective synonym of *A*. *dorotheae*, stating that it merely represented a "middle stage" ontogenetic variation within *A*. *dorotheae*.

In 1989, Murry described a new assemblage of 32 ceratodontoid lungfish tooth plates from Upper Triassic strata in the "upper Petrified Forest Member" (Painted Desert Member, of some usage) within PEFO (Fig. 1). These consisted of 30 plates from the Lungfish locality (PFV 190), and one additional tooth plate each from the Flattops (PFV 187) and Dinosaur Hill (PFV 040) localities. Murry (1989) utilized the method established by Vorob'yeva and Minikh (1968) as well as the phylogenetically informative characteristics of ceratodontoids proposed by Martin et al. 1981; Martin, 1982) to

identify (the species of lungfish found within PEFO. The method first performed by Vorob'yeva and Minikh (1968) consists of measuring a series of angles formed by the ridges of ceratodontoid tooth plates. These angles are based on a set of anchor points placed on the origin of the ridges and distal ends of the ridges, or atop the crests (Fig. 2E-F). Murry (1989) assigned all 32 PEFO plates in his assemblage as *Arganodus* sp., and deemed them most similar to *A. dorotheae* and *A. atlantis*. He notes that the Chinle specimens are closely related to *A. dorotheae* and may be synonymous (Murry, 1986; 1989). Murry (1989: 269) also hinted at further diversity, stating that, "the variability of the internal angle is evidently unlike the condition seen in the arganodontids, and this character is somewhat reminiscent of the ptychoceratodontids." He (Murry, 1989: 269) also stated that, of the characters he used, "eight characters total are shared with at least some of the specimens Martin classifies as arganodontids, seven characters in common with at least some of the ptychoceratodontids…" Thus, while largely continuing to identify Triassic lungfish tooth plates from the American Southwest as *Arganodus*, he also acknowledged the possibility that there was more than one taxon represented in the assemblage.

More recently, Heckert et al. (2012) documented Upper Triassic lungfish tooth plates from the Cumnock Formation in the Newark Supergroup of North Carolina that they assigned to *Asiatoceratodus*, following Kemp (1998), who synonymized *Arganodus* with *Asiatoceratodus*, but many authors reject this hypothesis and instead retain *Arganodus* as a separate genus (Schultze, 2004; Cavin et al., 2007; Soto and Perea, 2010; Skrzycki 2015). Following this logic, essentially all Upper Triassic lungfish tooth plates from mainland North America have been assigned to *Arganodus* (=*Asiatoceratodus*), with *A. dorotheae* the nominal species, although authors such as Murry (1989) have suggested that some tooth plates are not readily assigned to *Arganodus* and thus there may be greater diversity.

THE HOMESTEAD SITE: A NEW LUNGFISH LOCALITY

The Homestead Site at Garita Creek is located in the Upper Triassic Garita Creek Formation (Fig. 1, 3), which occurs in the middle of the Chinle Group of east-central New Mexico, following the stratigraphic terminology of workers in the region (Lucas et al., 2001; Lucas, 2004). During the Late Triassic, a continental river system drained northwest across the Four Corners region of North America into the Proto-Pacific Ocean (Dubiel, 1989; Lucas, 1993; Riggs et al., 1996; Fiorillo et al., 2000; Cleveland et al., 2008). This river system led to the deposition of Chinle sediments across the southern Colorado Plateau throughout the Norian and into the Rhaetian (Dubiel, 1989; Lucas, 1993; Cleveland et al., 2008; Martz and Parker, 2010; Martz et al., 2017). The Chinle, variously referred to as a formation (e.g., Stewart et al., 1972; Dubiel, 1989) or group (e.g., Lucas, 1993; Lucas et al., 2001), consists mainly of mudstone-dominated slopes and sandstone-dominated benches (Lucas et al., 2001). This is consistent with the lithology of the Garita Creek Formation, which is mostly silty/sandy mudstone slopes containing limestone nodules interrupted by massive, fine-grained sandstone-dominated benches with some laminations and ripples (Lucas and Hunt,

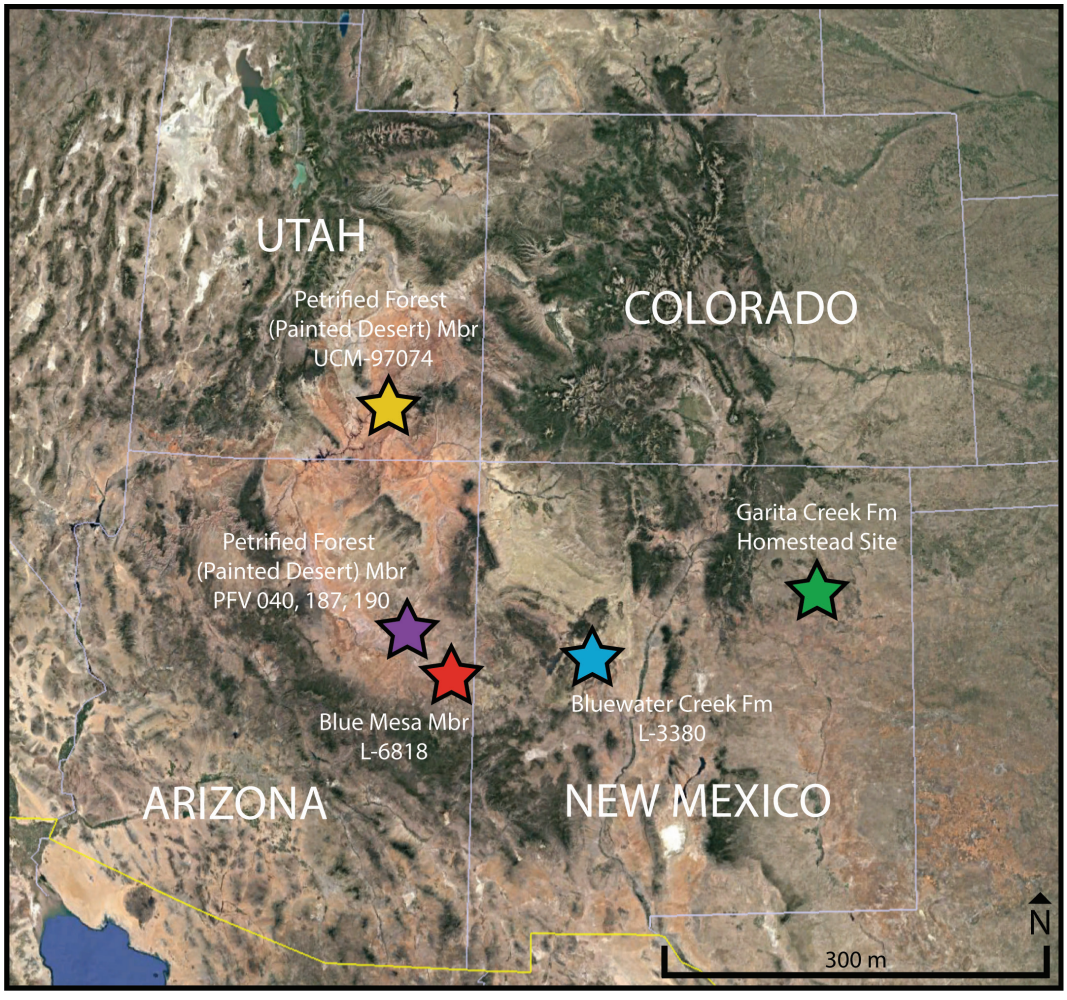


FIGURE 1. Map of the Four Corners region in the southwestern United States, showing the location of Upper Triassic lungfish localities used in this study. Includes the new locality, the Homestead Site of the Garita Creek Formation; NMMNH L-3380 of the Bluewater Creek Formation; NMMNH L-6818 of the Blue Mesa Member; and UCM-97074 of the Petrified Forest Member. PEFO localities PFV 040 (Dinosaur Hill), PFV 187 (Flattops), and PFV 190 (Lungfish Locality) used by Murry (1989) indicated as well. Image captured via Google Earth.

1989; Fig. 3). Lucas et al. (2001) provided a detailed review of the history of stratigraphic nomenclature in the region.

Local Stratigraphy. — The exposed section of Homestead is only 7.45 m thick, with a 0.35 m thick fossiliferous horizon found at the base of the section; it is located 7.2 km northwest from the type section of Garita Creek and less than 4.8 km southwest from the Mouth of Garita Creek (MoGC) section (Fig. 3). The type section of the Garita Creek Formation is 71 m thick and the MoGC section is 88 m thick, the latter of which is located approximately 13 km northwest of the type section (Fig. 3). The Homestead site is hypothesized to correlate 14-24 m above the base of the type section and 6 m above the base of the MoGC section, based on correlation of the local section near the site to a persistent bench-forming sandstone (Fig. 3). This puts the Homestead site approximately 70 m below the top of the Garita Creek Formation locally.

Biostratigraphy and Age. — Lucas and Hunt (1989) named the Garita Creek Formation, and shortly thereafter Hunt et al. (1989) reported a fragmentary assemblage of vertebrate fossils from this outcrop belt. Thus far, this remains the only published vertebrate assemblage from the outcrop belt associated with the type section, although there are some other incidental fossil occurrences in the eastern Garita Creek Formation (Lucas et al., 2001). Based on these fossils and others farther to the west, Lucas et al. (2001; Lucas, 2004) considered the Garita Creek Formation to be of Adamanian (early Norian) age.

Farther to the west, the Garita Creek Formation hosts the world-famous Lamy metoposaur mass death assemblage (see Lucas et al., 2010; Hegrón et al., 2020). Until discovery of the Homestead site, the Lamy quarry and other nearby localities yielded the only fossils of the Garita Creek Formation that are age-diagnostic beyond "Late Triassic." Lucas et al. (2001, 2010) considered the Garita Creek Formation to be Adamanian based on this assemblage, a conclusion echoed by Martz and Parker (2017). Hegrón et al. (2020) similarly considered the Garita Creek Formation to be Adamanian in age, although their argument was based on the presence of azendohsaurids and tanystropheids, and thus was more of a stage of evolution argument. However, Pritchard et al. (2015) recorded the presence of tanystropheids in the Revueltian-aged Hayden Quarry of Ghost Ranch in northern New Mexico, thus casting doubt on using the presence of tanystropheids for differentiating between the Adamanian and Revueltian. Previously Hunt et al. (2005) coined the term "Lamyan" to indicate that the quarry's assemblage represented a younger interval of Adamanian time, based on fossils from the stratigraphically lower Tres Lagunas Member of the Santa Rosa Formation (assigned by them to the aetosaur *Typothorax antiquum* and the phytosaur *Pseudopalatus* sp.), and proposed a tentative correlation to strata now identified as the Jim Camp Wash beds of the Sonsela Member in PEFO.

We note that the Adamanian age for the Garita Creek Formation is thus established based on fossils low in the formation from the western edge of its recognized outcrop belt. With many thousands of microvertebrate and some larger fossils available, we tentatively consider the Homestead site to be of Revueltian (early-mid Norian; Revueltian teilzone of Martz and Parker, 2017). We base this argument principally on the presence of the index fossil *Reticulodus synergus*, a

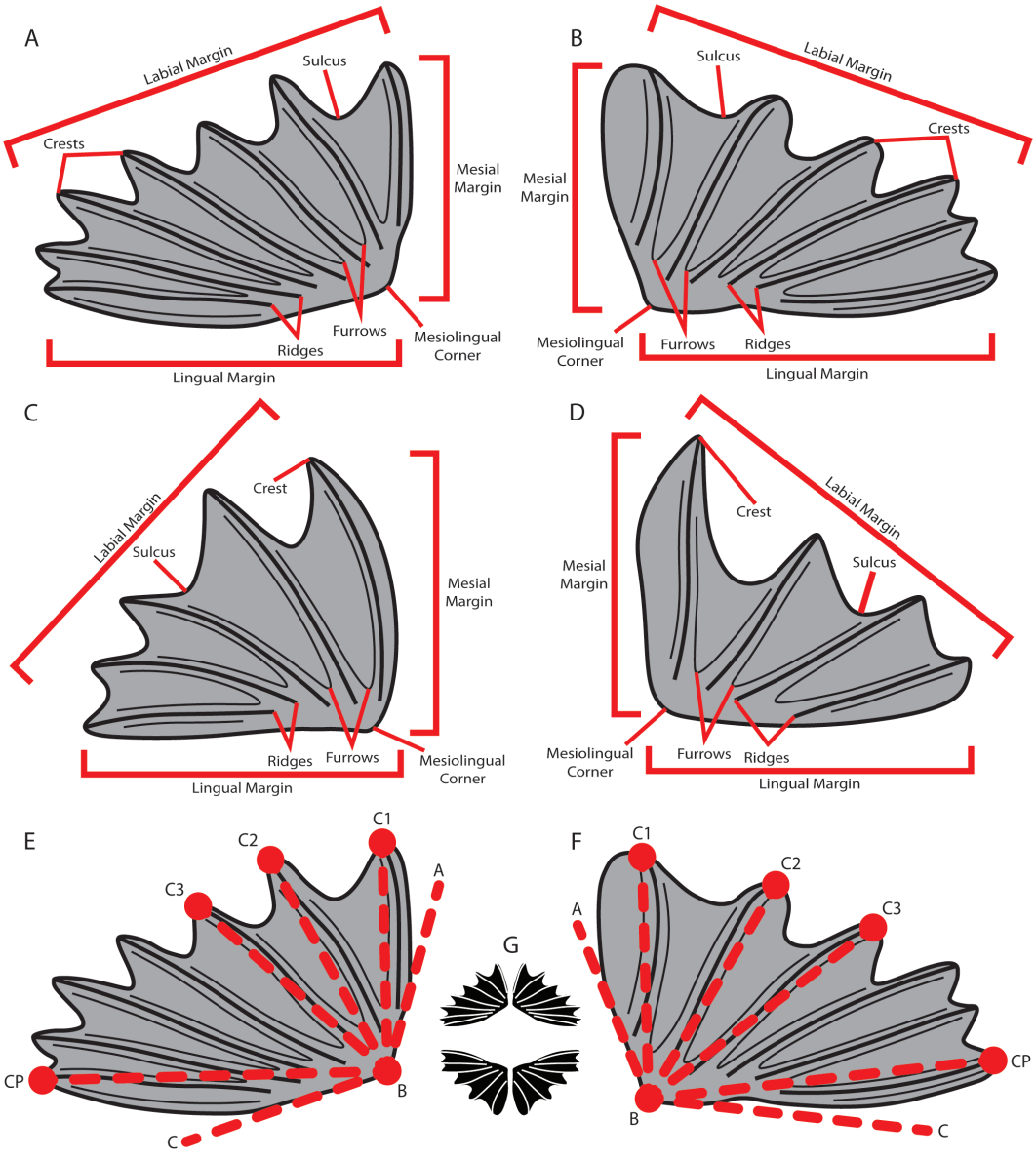


FIGURE 2. Lungfish tooth plate orientation and nomenclature. A–B: *Arganodus* right palatal (A) and right splenial (B) tooth plates based on Murry (1989, fig. 6). C–D: *Ptychoceratodus* right palatal (C) and right splenial (D) tooth plates based on Skrzycki et al. (2018, fig. 3). Terminology associated with the different margins and morphological features based on Kemp (2002) and Churcher et al. (2006). "Mesiolingual corner" follows Frederickson and Cifelli (2017). E–F: Schematics showing the orientation of specific crests and other features as measured in *Arganodus* by Murry (1989). G: 180° view of *Arganodus* palatal and splenial plates oriented within the mouth, based on Murry (1989, fig. 6).

durophagous hybodont shark with superficially batoid-like teeth known primarily from strata of Revueltian age in the American Southwest (Murry and Kirby, 2002; Heckert and Lucas, 2006; Voris and Heckert, 2017). Voucher specimens of *Reticulodus* from the Homestead Site include LF 5513-17 and LF 5535. We also note that, while there are many thousands of microvertebrate fossils still undergoing organization and curation, thus far we have not identified any characteristically Adamanian microvertebrates, such as *Triodus moorei*, *Colognathus*, *Crosbysaurus*, or *Krzyzanowskisaurus* (e.g., Heckert and Lucas, 2006) from the assemblage. Presently, all larger tetrapods from the assemblage are fragmentary, but osteoderm fragments of aetosaurs from the site (e.g., LF 5536) are more consistent with assignment to *Typothorax*, which may occur in the uppermost strata of Adamanian age (e.g, Parker and Martz, 2011), but is more characteristic of Revueltian assemblages.

Sedimentology. — Based on the fine-grained, predominantly dark, but somewhat color-mottled strata, we hypothesize that Homestead was an oxbow lake or other ephemeral water body that filled in with sediment and underwent soil formation (Dubiel, 1989; Fiorillo et al., 2000). The majority of sediments that make up the fossiliferous interval are fine-grained silts and clays. This fine-grained matrix, along with the color mottling of the mudstone, implies there were many periods of seasonal drought within a low energy depositional environment (Dubiel, 1991; Firoillo et al., 2000; Therrien and Fastovsky, 2000; Cleveland et al., 2008). Intermittent drought would have caused the water table to fluctuate, resulting in alternating anoxic and aerobic conditions that produce reduced and oxidized iron compounds, which is represented by the greenish-gray and reddish-brown mudstone (Dubiel, 1991; Fiorillo et al., 2000; Therrien and Fastovsky, 2000; Cleveland et al., 2008).

Taphonomy. — A wide variety of microvertebrate fossils are preserved within the fossiliferous bed at Homestead. These fossils range from <0.5 mm to >4 mm in size, though the majority found are 1–2 mm. Few fossils are actually found *in situ*, as the fossiliferous bed weathers out into a shallow slope called the "wash." This "wash" extends out beyond the exposed section into an area called the "South Mesquite," which contains some stratigraphically lower, but *in situ* fossils in a sandy siltstone/fine-grained sandstone. These fragile elements are disarticulated but undistorted, preserving a great amount of detail that aids in taxonomic identification. There are many specimens from Homestead diagnostic to at least the genus level, such as the aforementioned *Reticulodus synergus*, the lungfish described here (Fig. 4A–H), but the site is dominated by diverse tetrapods (Heckert et al., 2023).

The most common fossils found at Homestead are coprolites. Some of these coprolites contain fish scales, or on rare occasions, bone and teeth. The picked bag collection is heavily biased against coprolites as well as fish material. It was not until the concentrate was provided that most of the coprolites and fish fossils were accounted for. However, due to the diagnostic shape and texture of lungfish tooth plates, most lungfish material at Homestead was recovered from the picked bags. The large number of fish fossils preserved at Homestead suggests that a stable body of water must have been present, at least temporarily, and assuming that Homestead was part of an

oxbow lake based on our sedimentological observations, the vast number of tetrapods that are preserved here may have been attracted to the ephemeral nature of this lacustrine region due to the fluctuating water table resulting from seasonal drought (Dubiel, 1991; Fiorillo et al., 2000). Periodic flooding may explain how many of the principally non-aquatic tetrapods were preserved at Homestead (Dubiel, 1991; Fiorillo et al., 2000; Therrien and Fastovsky, 2000), but we are not able to support any of these suggestions without further study.

SITE COMPARISONS

The Homestead site is now the second most prolific lungfish tooth plate site in the Upper Triassic of North America of which we are aware, following Murry's (1989) "lungfish locality" (PFV 190, Fig. 1). Thus, in studying the tooth plates here, we relied on first-hand comparison to tooth plates from other sites in New Mexico, Arizona, and Utah, as well as comparisons to the specimens described and illustrated by Murry (1989).

The other New Mexico locality is in the Lucero uplift of central New Mexico and is NMMNH locality 3380 (NMMNH L-3380, Fig. 1). This and two other nearby localities are in low exposures of the Bluewater Creek Formation. The vertebrate assemblage from these localities was previously described by Heckert (1997) and Zeigler et al. (2002), who considered them to be Adamanian (early Norian) in age. The tooth plates from Arizona were collected from a region known as the "Blue Hills," slightly northeast of St. Johns. This area is well known for its tetrapod fossils, dating back to Charles L. Camp's collections in the 1920s (Long et al., 1989; Long and Murry, 1995; Heckert et al., 2005).

The lungfish fossils described here were collected from NMMNH locality 6818 (NMMNH L-6818, Fig. 1), low in the Blue Mesa Member amongst many other fossils of well corroborated Adamanian (early Norian) age (Heckert et al., 2005). The three localities in Arizona that were sampled by Murry (1989, Fig. 1) are all located in the Petrified Forest Member (Woody, 2006; Martz et al., 2012), also referred to as the Painted Desert Member by some (Lucas, 1993; Heckert and Lucas, 2002), and are stratigraphically above the other Adamanian localities (Martz and Parker, 2017, fig. 14). The Petrified Forest Member in PEFO, including all of Murry's (1989) sites is of well-corroborated Revueltian age (Heckert and Lucas, 2002; Parker and Martz, 2011; Martz and Parker, 2017). The Utah fossils were collected from strata exposed in the Red Canyon area and originally described by Parrish and Good (1987) and Parrish (1999). This particular locality is known as the Four Aces Mine, reposited at UCM, and the site is designated as UCM-97074 (Fig. 1). This locality also lies in the Petrified Forest Member (Painted Desert Member of some usage), which is probably stratigraphically equivalent to the Petrified Forest Member in PEFO and also considered to be Revueltian in age (e.g., Martz et al., 2017). All three specimens from this locality were cataloged under a single number (UCM 76502) so we distinguish between them as 76502-A, 76502-B, and 76502-C.

SYSTEMATIC PALEONTOLOGY

OSTEICHTHYES Huxley, 1880

SARCOPTERYGII Romer, 1955

DIPNOI Müller, 1844

CERATODONTIFORMES Berg, 1940

Description. — Within the assemblage of 18 tooth plates from Homestead (Fig. 4A–R; Appendix 1), we identify a total of nine palatal tooth plates (six left, three right) and four splenial tooth plates (two left, two right). Five of the 18 plates have an unclear palatal/splenial position due to strong wear, fracturing, or lack of attached bone, and thus are considered positionally "ambiguous;" tentatively two are splenial and three are palatal. Palatal and splenial tooth plates can be distinguished based on several characteristics. In palatal plates, the mesial margin is not "inflated" outward from the anteriormost ridge in occlusal view, the lingual and labial profile declines posteriorly, and/or remnants of the pterygopalatine bone/ascending process can be seen (Murry, 1989; Fig. 2A, C). In splenial plates, the mesial margin is "inflated" outward from the anteriormost ridge in occlusal view, the lingual and labial profile is concave or straight, and/or remnants of the prearticular bone/sulcus is present (Murry, 1989; Skrzycki, 2015; Fig. 2B, D). The total ridge count may also be used to distinguish between palatal and splenial plates, with *Arganodus* specifically ranging from 6-8 for palatal and 6-7 for splenial (Skrzycki, 2015).

The tooth plates from Homestead (Fig. 4A–R) are relatively typical of Upper Triassic lungfish tooth plates from the American Southwest, having a morphology that would traditionally be classified as *Arganodus* sp. The ridges originate anteriorly and radiate outwards, forming a fan-like occlusal surface, the ridges are all roughly similar in how slender and acute they are, unlike in some taxa where they are much more robust, and are generally triangular in overall shape (Skrzycki, 2015; Skrzycki et al., 2018). 16 of the 18 plates have 5-7 total ridges, which historically was considered to align with *Arganodus* (Murry, 1989), however, a total of five ridges is no longer considered a feature of *Arganodus* (Skrzycki, 2015), suggesting another taxa is present. This will be explained in further detail in the following section.

We have identified a total of nine different morphologies based on the positioning (palatal vs splenial) and total ridge count of the tooth plates: 1) 8-ridged palatal (LF 5726; e.g., Fig. 4G); 2) 7-ridged palatal (LF 5720, 5721, 5724, 5725; e.g., Fig. 4A); 3) 7-ridged splenial (LF 5722, 6272; e.g., Fig. 4H); 4) 6-ridged palatal (LF 5723; e.g., Fig. 4D); 5) 6-ridged splenial (LF 6273; e.g., Fig. 4R); 6) 6-ridged ambiguous (LF 5728, 5729; e.g., Fig. 4J); 7) 5-ridged palatal (LF 5731, 5732, 5733; e.g., Fig. 4N); 8) 5-ridged ambiguous (LF 5727, 5734, 5735; e.g., Fig. 4I); 9) 4-ridged splenial (LF 5730; e.g., Fig. 4L).

There is a wide variety of minor character variations preserved within the Homestead assemblage. These may include the distinctiveness of the mesiolingual corner (anchor point B) or ridge crests, how obtuse the mesiolingual angle (anchor points ABC) is, curvature of the mesial and lingual margins, declination of the labial margin, width or depth of the sulci, depth of the furrows, height and length of the ridges, radiation of the

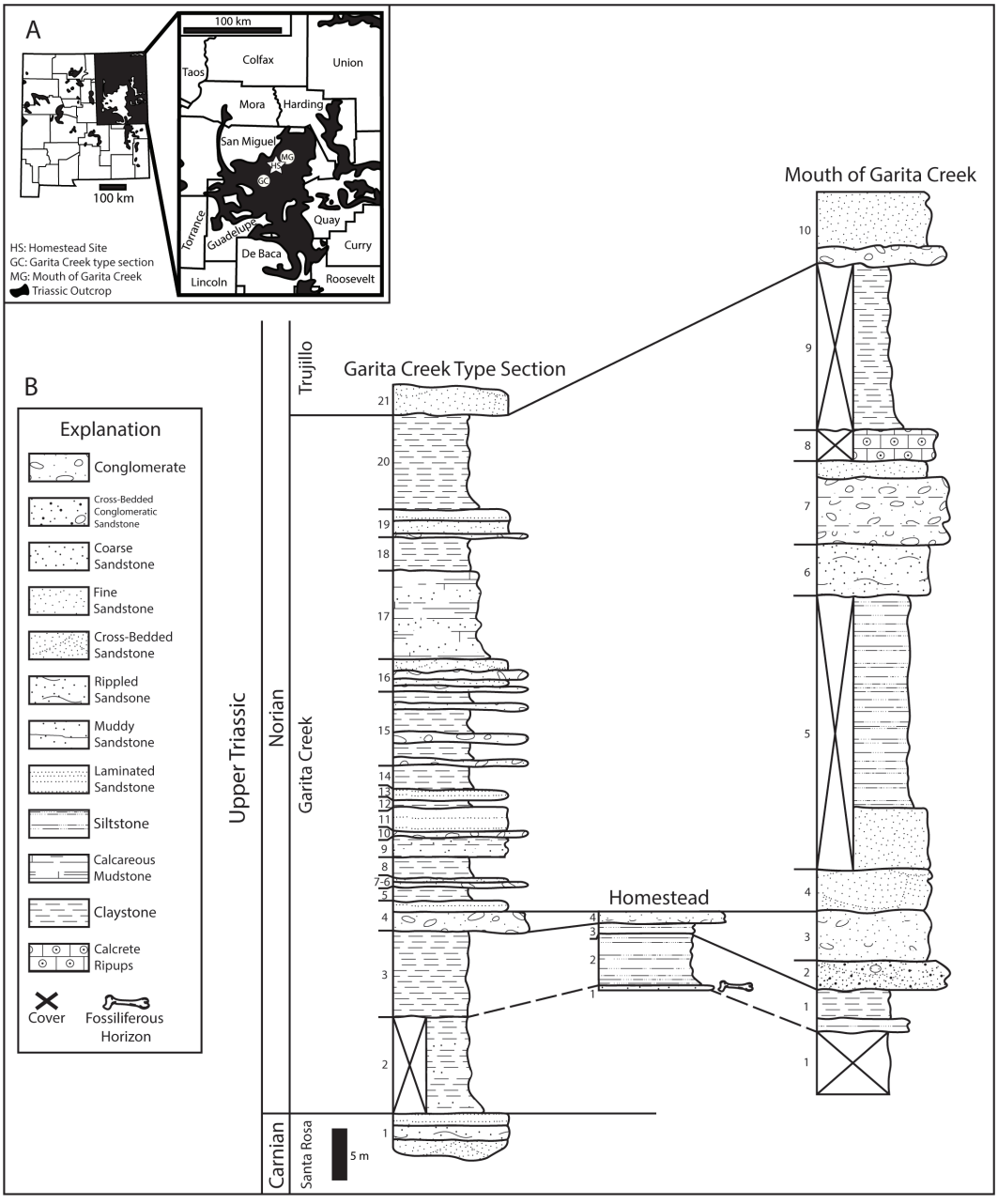


FIGURE 3. A: Index map of New Mexico, United States, showing the location of the Homestead Site stratigraphic section (**HS**), Garita Creek type section (**GC**), and Mouth of Garita Creek section (**MG**). B: Stratigraphic correlation of the Homestead Site to the Garita Creek type section and Mouth of Garita Creek section. Lithological explanation shown on left-side, along with columns representing the geologic epoch, age, and formation for the correlations. Representative lithologies sampled in largely covered intervals are shown to the right side of the column.

ridges, length of the anteriormost ridge compared to the second, inflation of the anteriormost ridge, definition of the posteriormost ridge, and the presence of ridge denticles, as well the color preserved in the tooth plate (Fig. 2, 4). Many of these variations in the plates are affected by the number of ridges, preservation, and wear facets. In terms of size, the 18 total tooth plates range from 2.2 to 23.1 mm in length and 1.8 to 13.4 mm in width. Notably, specimens LF 5728-35 (Fig. 4J-Q) from Homestead are distinctively smaller than the rest of the assemblage, ranging from 2.2 to 6.1 mm in length and 1.8 to 3.5 mm in width. Additionally, LF 5720 (Fig. 4A) from Homestead, while not as small, is still only 8.5 mm long and 4.7 mm wide; all others are at least 11.1 mm long and 6.9 mm wide.

The total number of ridges preserved in the tooth plates ranges from 4-8. Only one specimen, LF 5730 (Fig. 4L) bears four ridges, and only one specimen, LF 5726 (Fig. 4G) bears eight ridges. The majority of plates in the assemblage possess either seven or five ridges. Specimens LF 5720-22, LF 5724-25, and LF 6272 (Fig. 4A-C, E-F, H) have seven ridges. Specimens LF 5727, and LF 5731-35 (Fig. 4I, M-Q), have five ridges. The rest of the plates, LF 5723, LF 5728-29, and LF 6273 (Fig. 4D, J–K, R) have six ridges. Due to wear or fracturing, many of the plates have a poorly defined posteriormost ridge. LF 5721 (Fig. 4B) is counted as having seven ridges, though there appears to be remnants of what looks like an additional 8th ridge. LF 5727 (Fig. 4I), which has a peculiar morphology overall, with its broadly curved mesial/lingual margins and near-flat ridges, may possess a 6th ridge. LF 5735 (Fig. 4Q) has the most wear of the plates in the assemblage, and combined with its near-flat ridges, may also possess a 6th ridge.

Comparisons. — Specimens LF 5720-26 and LF 6272 (Fig. 4A–H) from Homestead appear to more closely resemble the eight non-Homestead tooth plates from localities L-3380, L-6818, and UCM-97074. NMMNH P-90530 (Fig. 4S) resembles the 7-ridged palatal morph; NMMNH P-90532 and UCM-76502-B (Fig. 4U, Y) resemble the 7-ridged splenial morph; NMMNH P-90533 (Fig. 4V) resembles the 6-ridged palatal morph; NMMNH P-90531, P-90534, and UCM-76502-A, C (Fig. 4T, W–X, Z) resemble the 6-ridged splenial morph. Out of these 16 tooth plates, they range from 8.5 to 23.1 mm in length and 4.7 to 13.4 mm in width, and consist of 6–8 total ridges.

Specimens LF 5727-35 and LF 6273 (Fig. 4I–R) from Homestead, when compared to the 16 other tooth plates in the Chinle assemblage, have differences from the rest of the assemblage that indicate a separate taxa present at Homestead, which we interpret to be a ptychoceratodontid. Species of *Arganodus* and *Ptychoceratodus* share many overlapping morphological features in their tooth plates that make distinguishing between them difficult (Murry, 1989; Skrzycki, 2015). According to Skrzycki (2015), a tooth plate bearing fewer than six ridges cannot be assigned to the genus *Arganodus*. Specimens LF 5727 and LF 5731-35 (Fig. 4I, M–Q) have five total ridges, and LF 5730 (Fig. 4L) has four total ridges. Individuals of *Ptychoceratodus* have 5–6 ridges for their palatal tooth plates and 4–6 for their splenial tooth plates, while individuals of *Arganodus* have 6–8 ridges for their palatal tooth plates and 6–7 for their splenial tooth plates (Skrzycki, 2015).

Because the Homestead assemblage includes tooth plates with as few as 4–5

ridges, it almost certainly includes an additional dipnoan taxon besides *Arganodus*. All other specimens within the Chinle assemblage range from 6-8 total ridges, which does align with the number of ridges present among arganodontids (Skrzycki, 2015). These include LF 5728-29 (Fig. 4J–K) and LF 6273 (Fig. 4J–K, R) from Homestead, which have six ridges. LF 5728-29 (Fig. 4J–K) are more similar to LF 5730-35 (Fig. 4L-Q) due to their smaller size compared to the rest of the assemblage. LF 5728 (Fig. 4J) has a broadly curved mesial/lingual margin similar to LF 5727 (Fig. 4I), and LF 6273 (Fig. 4R) has a noticeably longer, inflated first ridge, much like LF 5730 (Fig. 4L).

Additionally, LF 5726 (Fig. 4G) has eight total ridges, which is an atypical feature of lungfish known from the Upper Triassic of North America (along with the four total seen in LF 5730, Fig. 4I); these tooth plates commonly have 5–7 ridges preserved (Case, 1921; Warthin, 1928; Huber et al., 1993; Murry, 1989; Heckert, 2004; Milner et al., 2006). While eight ridges still aligns with *Arganodus*, it is typically seen in individuals of *A. atlantis* known from the Late Triassic of northern Africa, whose palatal plates may possess eight ridges, compared to *A. dorotheae*, which normally has seven (Case, 1921; Skrzycki, 2015; Skrzycki et al., 2018).

ARGANODONTIDAE Martin, 1982

ARGANODUS Martin, 1979

ARGANODUS sp.

Figure 4A–H

Diagnosis. — The following diagnosis is based on the tooth plate characters presented by Skrzycki (2015, table 5). Tooth plates triangular and high-crowned with wide pulp cavity; limited mantle dentine visible on occlusal surface; short radiating ridges originate anteriorly; six to eight ridges on upper tooth plate, six to seven on lower; upper tooth plates contiguous in the midline, lower close or in contact; upper symphysis oval, lower linear; ascending process of pterygopalatine bone originating between second and third ridges; petrodentine absent.

Referred Specimens. — LF 5720-26, LF 6272.

Fossils we are comfortable assigning to *Arganodus* here have 6-8 ridges on their palatal tooth plates and 6-7 on their splenial tooth plates (Skrzycki, 2015). Comparisons of these plates to other "typical" Upper Triassic lungfish tooth plates (Fig. 4S-Z) show relatively consistent proportions, ridge counts, and other features.

PTYCHOCERATODONTIDAE Martin, 1982

PTYCHOCERATODUS Jaekel, 1926

cf. *PTYCHOCERATODUS*

Figure 4I–R

Diagnosis. — The following diagnosis is restricted to tooth plate characters and was presented by Skrzycki (2015: e964357-3). "...tooth plates triangular and high-crowned with wide pulp cavity; limited mantle dentine visible on occlusal surface; short radiating ridges originate anteriorly; five to six ridges on upper tooth plate, four to six on lower; upper tooth plates close or contiguous in the midline, lower close; upper symphysis oblong, lower linear; ascending process of pterygopalatine bone originating

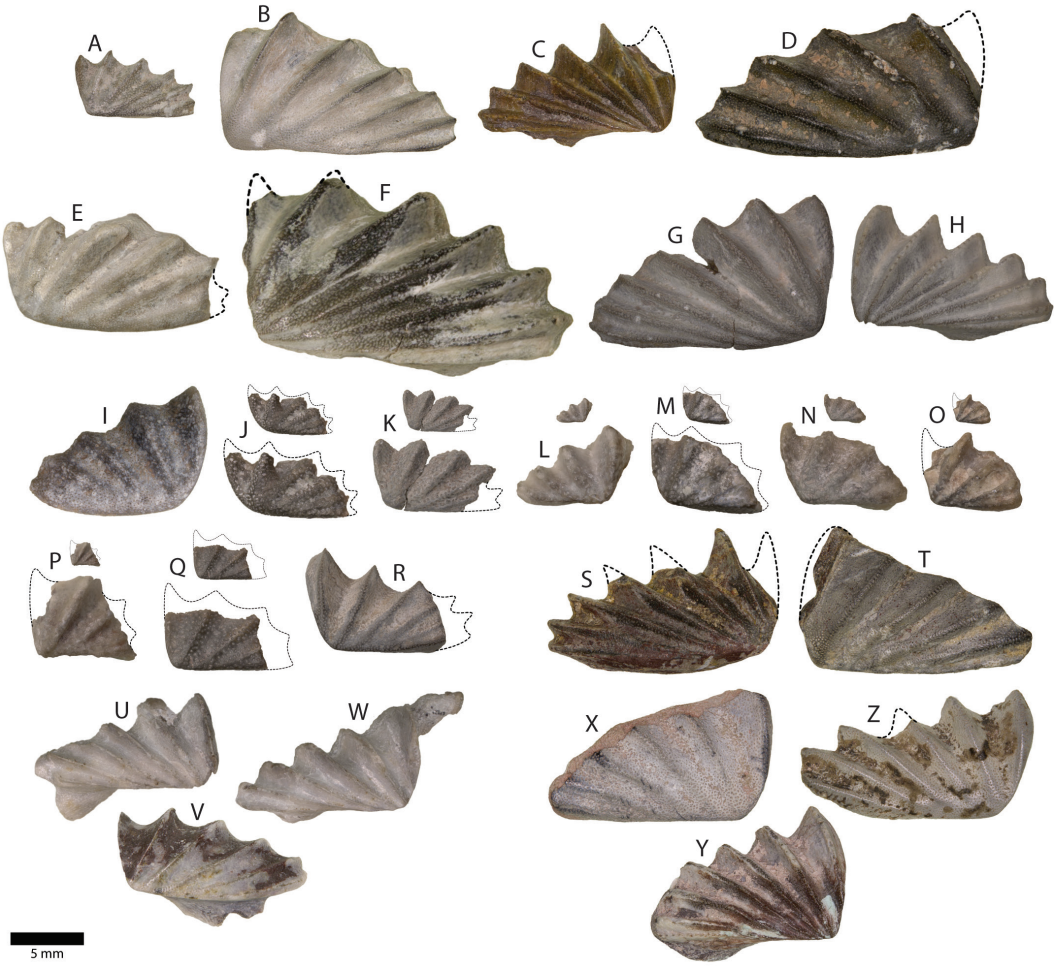


FIGURE 4. Assemblage of 26 lungfish tooth plates from four Upper Triassic Chinle localities. All tooth plates pertain to *Arganodus* sp. unless specified. LF 5720-26, LF 6272 (A–H): Homestead Site, Garita Creek Formation; NMMNH P-90530, P-90531 (S–T): NMMNH L-3380, Bluewater Creek Formation; NMMNH P-90532, P-90533, P-90534 (U–W): NMMNH L-6818; Petrified Forest Formation; UCM-76502-A, B, C (X–Z): UCM-97074, Petrified Forest Formation. Specimens LF 5727, 5728, 5729, 5730, 5731, 5732, 5733, 5734, 5735, and LF 6273 (I–R) belong to the cf. *Ptychoceratodus* morphology of Homestead; LF 5728-35 showcase original size and upscaled version to show detail. Dashed outlines represent proposed reconstructions. See Appendix 1 for details of positional assignments.

above the second ridge of upper tooth plate or between second and third ridges; petrodentine absent."

Referred Specimens. — LF 5727-35, LF 6273.

Specimens possessing only 4–5 ridges fall outside the currently accepted range of variation for *Arganodus*, and instead most closely resemble *Ptychoceratodus* (Skrzycki, 2015). Due to the similar morphology in the plates of *Arganodus* and *Ptychoceratodus* (Fig. 2, 4), the main distinguishing character is the total number of ridges present, although there is some overlap, as both genera may have six ridges per plate (Skrzycki, 2015). The lack of cranial material prevents any species assignments from being made, so tentatively, we consider the larger morph as still representing *Arganodus* sp., while the generally smaller morph is best designated as cf. *Ptychoceratodus*. The possibility remains that some six-ridged individuals of the second morph may be smaller individuals of the first morph in actuality. Using these same criteria, we recognize two taxa in the sample described by Murry (1989). While the vast majority of the specimens he (Murry, 1989) described and illustrated are best assigned to *Arganodus*, those with only six ridges could conceivably be assigned to either *Arganodus* or *Ptychoceratodus*.

Importantly, Murry (1989) illustrated two tooth plates that have five or fewer ridges (PEFO 3860; Murry, 1989, fig. 6g-h; PEFO 3864, Murry, 1989, fig. 6j) that he assigned to "*Arganodus*?." Another three reported in his dataset (PEFO 3852, PEFO 3881, PEFO 3885; Murry, 1989, table 1) also only have five ridges. LF-5727 (Fig. 4I) from Homestead bears a striking resemblance to PEFO 3860 (Murry, 1989, fig. 6g-h), while NMMNH P-90530 (Fig. 4S) from L-3380 resembles PEFO 3857 (Murry, 1989, fig. 6c). Based on subsequent work, especially that of Kemp (1998), Cavin et al. (2007), Soto and Perea (2010), Skrzycki (2015), and sources cited therein, we tentatively consider these teeth to also represent a taxon more closely related to *Ptychoceratodus* than *Arganodus*.

CONCLUSIONS

For decades essentially all lungfish tooth plates recovered from Upper Triassic strata in North America were assigned to *Arganodus*. Detailed examination of specimens from prolific sites, such as Murry's (1989) lungfish locality and the Homestead site fossils documented here indicates that, while the majority of fossil tooth plates from the Upper Triassic of North America can be assigned to *Arganodus*, there is likely at least one additional taxon present, one best considered as cf. *Ptychoceratodus*.

The genus *Ptychoceratodus* has a limited record within North America. A single occurrence of *P. rectangulus* is known from the Upper Triassic Fleming Fjord Formation of east Greenland, a taxon first described from the middle-upper Norian of Germany (Pawlak et al., 2020). *Ptychoceratodus* was abundant during the Late Triassic, occupying an extensive geographic range across Pangea where it inhabited a variety of climatic settings (Skrzycki et al., 2018). Multiple species are known from various localities across the southern Central European Basin, Argentina, Brazil, Madagascar, Turkey, and India (Schultze, 2004; Skrzycki, 2015; Skrzyckiet al., 2018). Occurrences of *Ceratodus guentheri*, a species compared favorably to *Ptychoceratodus* by Martin (1982), are known from the Jurassic Morrison Formation of the U.S.A.

(Milner and Kirkland, 2006; Frederickson and Cifelli, 2017), but was later assigned to the genus *Potamoceratodus* by Pardo et al. (2010). Additionally, some lungfish tooth plates with a "ptychoceratodont" morphology are known from Cretaceous deposits of the western U.S.A. (Frederickson and Cifelli, 2017; Skrzycki et al., 2018). The presence of a ptychoceratodontid within the Chinle Group would help explain the multiple appearances of these ptychoceratodontids in post-Triassic strata of North America. As suggested by Skrzycki et al. (2018), representatives of *Ptychoceratodus* likely expanded westward from Great Britain to reach North America, possibly starting from Greenland, as there was some connection between Europe and North America until the Jurassic.

The geographic range of both *Arganodus* and *Ptychoceratodus* are quite extensive throughout the Mesozoic, occurring across Pangea (Skrzycki et al., 2018; Pawlak et al., 2020). Both genera are known to have coexisted with each other in the Early Triassic of Russia and Australia (Skrzycki et al., 2018). The occurrence of cf. *Ptychoceratodus* in the Upper Triassic Chinle Group would extend the range of the "ptychoceratodont" morphology into the southwest U.S.A., and shows that they coexisted with *Arganodus* in basins that are now on at least three modern continents. Therefore, *Arganodus* would no longer be the solely represented genus within the Late Triassic U.S.A.

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APPENDIX 1. Details of the new lungfish tooth plates described and illustrated in this paper.

Fig. 4	Catalog Number	Locality	Proposed Identification	Position	Ridge Count	Length (mm)	Width (mm)
A	LF 5720	Homestead	*Arganodus* sp.	Left Palatal	7	8.500	4.711
B	LF 5721	Homestead	*Arganodus sp.*	Left Palatal	7?	16.923	10.022
C	LF 5722	Homestead	*Arganodus sp.*	Left Splenial	7	14.183	7.763
D	LF 5723	Homestead	*Arganodus sp.*	Right Palatal	6	20.078	10.078
E	LF 5724	Homestead	*Arganodus* sp.	Left Palatal	7	16.712	7.591
F	LF 5725	Homestead	*Arganodus sp.*	Right Palatal	7	23.081	13.390
G	LF 5726	Homestead	*Arganodus sp.*	Right Palatal	8	17.321	11.116
H	LF 6272	Homestead	*Arganodus* sp.	Right Splenial	7	14.000	8.609
I	LF 5727	Homestead	cf. *Ptychoceratodus*?	Left Splenial?	5?	12.519	9.022
J	LF 5728	Homestead	cf. *Ptychoceratodus*?	Left Palatal?	6	6.064	3.490
K	LF 5729	Homestead	cf. *Ptychoceratodus*?	Left Palatal?	6	5.395	2.952
L	LF 5730	Homestead	cf. *Ptychoceratodus*	Left Splenial	4	2.407	1.790
M	LF 5731	Homestead	cf. *Ptychoceratodus*	Left Palatal	5	3.613	2.613
N	LF 5732	Homestead	cf. *Ptychoceratodus*	Left Palatal	5	3.026	1.932
O	LF 5733	Homestead	cf. *Ptychoceratodus*	Left Palatal	5	2.826	2.132
P	LF 5734	Homestead	cf. *Ptychoceratodus*	Right Splenial?	5	2.224	1.814
Q	LF 5735	Homestead	cf. *Ptychoceratodus*	Left Palatal?	5?	5.374	3.490
R	LF 6273	Homestead	cf. *Ptychoceratodus?*	Right Splenial	6	11.109	6.932
S	NMMNH P-90530	NMMNH L-3380	*Arganodus* sp.	Right Palatal	7	16.361	9.490

APPENDIX 1. (*continued*)

Fig. 4	Catalog Number	Locality	Proposed Identification	Position	Ridge Count	Length (mm)	Width (mm)
T	NMMNH P-90531	NMMNH L-3380	*Arganodus* sp.	Right Splenial	6	16.674	10.204
U	NMMNH P-90532	NMMNH L-6818	*Arganodus* sp.	Left Splenial	7	12.928	7.026
V	NMMNH P-90533	NMMNH L-6818	*Arganodus* sp.	Right Palatal	6	13.472	6.349
W	NMMNH P-90534	NMMNH L-6818	*Arganodus* sp.	Left Splenial	6	12.790	8.125
X	UCM-76502-A	UCM-97074	*Arganodus* sp.	Left Splenial	6	15.601	9.249
Y	UCM-76502-B	UCM-97074	*Arganodus* sp.	Left Splenial	7	13.308	9.307
Z	UCM-76502-C	UCM-97074	*Arganodus* sp.	Left Splenial	6	16.319	9.234

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