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EARLY PERMIAN FOSSIL FLORAS FROM THE RED BEDS OF PREHISTORIC TRACKWAYS NATIONAL MONUMENT, SOUTHERN NEW MEXICO

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Abstract—Early Permian (Wolfcampian), fossiliferous terrestrial red beds of the Abo Formation crop out in a north-to-south band through central New Mexico. Abo strata were deposited in entirely terrestrial settings and only in southern portions of the state do they intertongue with marine rocks of the Hueco Group. Here we focus on fossil floras from one of the areas where this close spatio-temporal intercalation of marine rocks and terrestrial red beds has been recognized, the Prehistoric Trackways National Monument located in the Robledo Mountains in Doña Ana County, south-central New Mexico. These strata are assigned to the Robledo Mountains Formation and are part of the upper Hueco Group. They are laterally equivalent to the upper part of the Abo Formation identified elsewhere in the state.

The floras of the Robledo Mountains Formation red beds are compositionally similar to those found in the Abo Formation. They are dominated by walchian conifers most similar to *Walchia piniformis*, a form taxon that may represent a number of distinct biological species. Isolated occurrences of other taxa include the peltasperm *Supaia thinnfeldioides*, the possible peltasperm *Gigantopteridium* sp., the cycadophyte *Taeniopteris* and callipterid peltasperms. The monotony of these Early Permian red-bed floras over a very large area is noteworthy and perplexing. Other facies from strata within this same time interval, elsewhere in the region, preserve either strikingly different floras or floras of considerably higher diversity. The red-bed floras do not appear to reflect a persistent preservational bias, but suggest that large areas were covered by low diversity forests of conifers. The proximity of the red-bed facies to marine conditions bordering the Hueco seaway does not seem to have had any discernible effect on their composition.

INTRODUCTION

The Early Permian was marked by a series of glaciations separated by periods of global warmth (e.g., Montañez et al., 2007; Fielding et al., 2008). In addition, the geological record indicates episodically increasing seasonality and climatic dryness around the equatorial regions of central and western Pangea (Kerp, 1996; Tabor and Poulsen, 2008; Tabor et al., 2013; Opluštil et al., 2013), a trend that began in the late Middle Pennsylvanian (Cecil et al., 1985). During this period of warming, terrestrial floras became increasingly heterogeneous spatially, which might be argued is an expectation in a world where generally increasing aridity magnifies habitat variability at all scales from the local landscape to broad regions.

One of the most westerly known Early Permian equatorial Pangean floras is found in the red beds of central New Mexico. These strata are terrestrial in origin and where there is no intercalation with marine strata are assigned to the Abo Formation (Lucas et al., 2005, 2013). In the southern parts of their outcrop area, however, along the Hueco seaway, Early Permian terrestrial red beds occur between beds of marine carbonate, recording oscillating cycles of climate and sea level (Mack et al., 2010). In this area, strata equivalent to the Abo Formation are classified as the Hueco Group. Of several Hueco Group formations, red beds and their associated plant and animal fossil assemblages are known only from the Robledo Mountains Formation, equivalent to the upper Abo and of Artinskian age.

In this paper we examine the flora of the Robledo Mountains Formation as preserved in the Prehistoric Trackways National Monument of southern New Mexico. These floras are of interest because they occur in terrestrial red beds preserved between marine strata. Evidence from trace fossils suggests that these red beds were deposited in relatively close proximity to marine environments (Voigt et al., 2013). They reemphasize the observation that the Abo Formation red beds, and their correlatives, contain a low diversity flora that is characteristic of this region, overwhelmingly dominated by walchian conifers.

LOCATION

The exposures examined in this study are located in the Prehistoric Trackways National Monument (PTNM). The PTNM is located within the Robledo Mountains, a small mountainous area to the northwest of Las Cruces, New Mexico, in Doña Ana County (Fig. 1). The PTNM is approximately 2140 hectares (approximately 8.25 square miles) in which principally Early Permian strata are exposed. It is administered by the US Bureau of Land Management.

GEOLOGICAL BACKGROUND

Lower Permian exposures in the Prehistoric Trackways National Monument are classified as the Hueco Group, a mixed marine carbonate – terrestrial siliciclastic unit. The Hueco Group is subdivided into four formations (Fig. 1) that are, from the base, the Shalem Colony, Community Pit, Robledo Mountains and Apache Dam (Lucas et al., 2005). The Shalem Colony, Community Pit and Apache Dam formations are composed predominantly of marine rocks; the Robledo Mountains Formation is mixed marine and terrestrial.

The Hueco Group is the lateral equivalent of the Abo and Yeso formations to the north (Lucas et al., 2013). The Abo Formation is divided into two members (Lucas et al., 2005), the lower Scholle Member and the upper Cañon de Espinoso Member. Both members are composed entirely of terrestrial lithofacies, primarily siliciclastics; carbonates in these rocks are pedogenic in origin. Within the Hueco Group, the Shalem Colony Formation is approximately correlative with the Scholle Member. The Community Pit, Robledo Mountains and lower quarter of the Apache Dam formations are the approximate correlatives of the Cañon de Espinoso Member. The upper portion of the Apache Dam Formation is laterally equivalent to the Yeso Group to the north. The Abo correlatives are considered to be of Wolfcampian age, and the Yeso equivalents of Leonardian age. Conodonts from the lower part of the Robledo Mountains Formation indicate an early Artinskian age for that formation (Lucas et al., 1998). This places the red beds and their floras in a time period variously classified as the end of Permian Glaciation II (Montañez et al., 2007), which is known by its proximate record primarily in western Australia (Fielding et al., 2008).

Fossiliferous red beds occur in one formation of the Hueco Group, the Robledo Mountains. At present, there are no known red-bed floras from the Shalem Colony, Community Pit or Apache Dam formations; floras from a brackish-water carbonate facies in the Community Pit Formation include allochthonous assemblages of walchian coniferophyte logs (Falcon-Lang et al., this volume) and a parautochthonous foliar macroflora (Falcon-Lang et al., submitted; DiMichele et al., this volume) of unique composition and depositional character. Floras are known from the red-bed facies through the entire

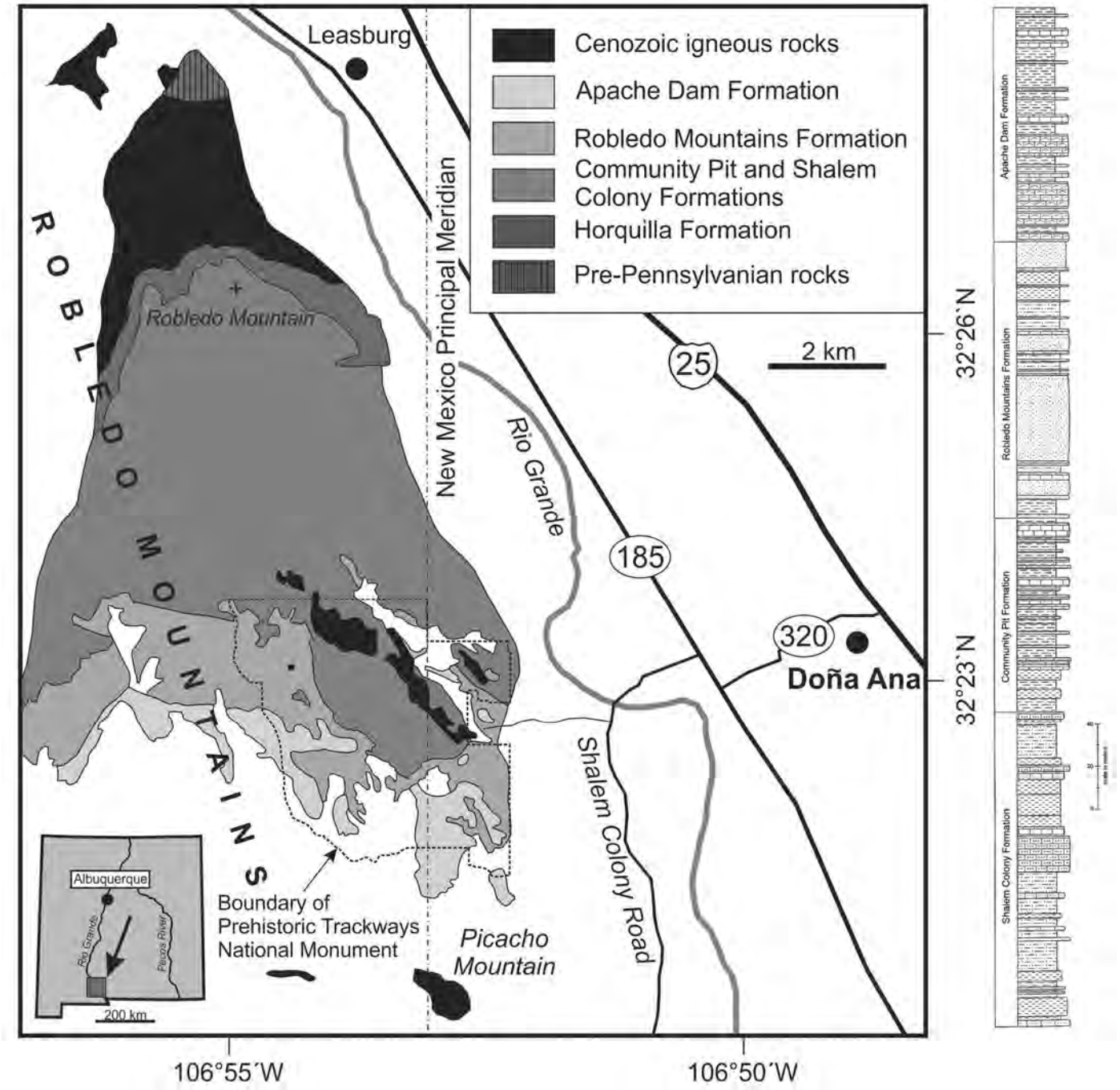


FIGURE 1. Location of the Prehistoric Trackways National Monument in southern New Mexico, within the Robledo Mountains. The fossiliferous red-bed deposits are within the Robledo Mountains Formation.

125 m thickness of the Robledo Mountains Formation.

Where it is best exposed, Robledo Mountains Formation characteristics suggest a strong background of external allogenic controls on large-scale patterns of sedimentation and sea level (Mack and James, 1986). At the highest level there is an alternation of marine and terrestrial facies; distinct red-bed successions, each 5 or more meters in thickness, alternate with marine carbonate beds. The red beds account for about one-third of the entire thickness of the formation and occur in approximately 5-7 discrete intervals (Voigt et al., 2013). Within the red-bed units (Figs. 2.1, 2.2), fluvial sandstone, siltstone and claystone (Mack, 2007) alternate with pedogenic horizons. Sandstone bodies indicate a predominance of sheet flow, with generally southerly flow directions (Voigt et al., 2013). Pedogenic horizons are variously developed, but comprise largely calcic Vertisols of polygenetic character indicative of long periods of surface exposure (Mack et al., 2010). The sandstone-siltstone-claystone layers, particularly where plant macrofossils and ichnofossil assemblages are most common, consist of alternating beds of siltstone to fine sandstone of tabular shape, generally flat bottomed, and thin clay layers, often little more than a few mm in thickness but in places up to several cm (Figs. 2.3, 2.4). The fossils are concentrated in the claystone layers (Fig. 3), but occur in the sandstones and siltstones at some places. The claystone beds show evidence of exposure in the form of mudcracks (Fig. 4), raindrop imprints, and rill marks; trackways of both invertebrates and vertebrates also are common and likely formed on wet exposed surfaces or in shallow water (Braddy, 1998; Lucas and Hunt, 2006; Minter and Braddy, 2009; Voigt et al., 2013). Plant fossils were found in three of the red bed intervals. These intervals account for a total thickness of approximately 25 m. Contacts between the red bed siliciclastics and limestones are abrupt. The carbonates appear to have formed in settings with poor circulation and or high salinity (Voigt et al., 2013). Overall, the features of both the siliciclasitics and carbonates are in conformance

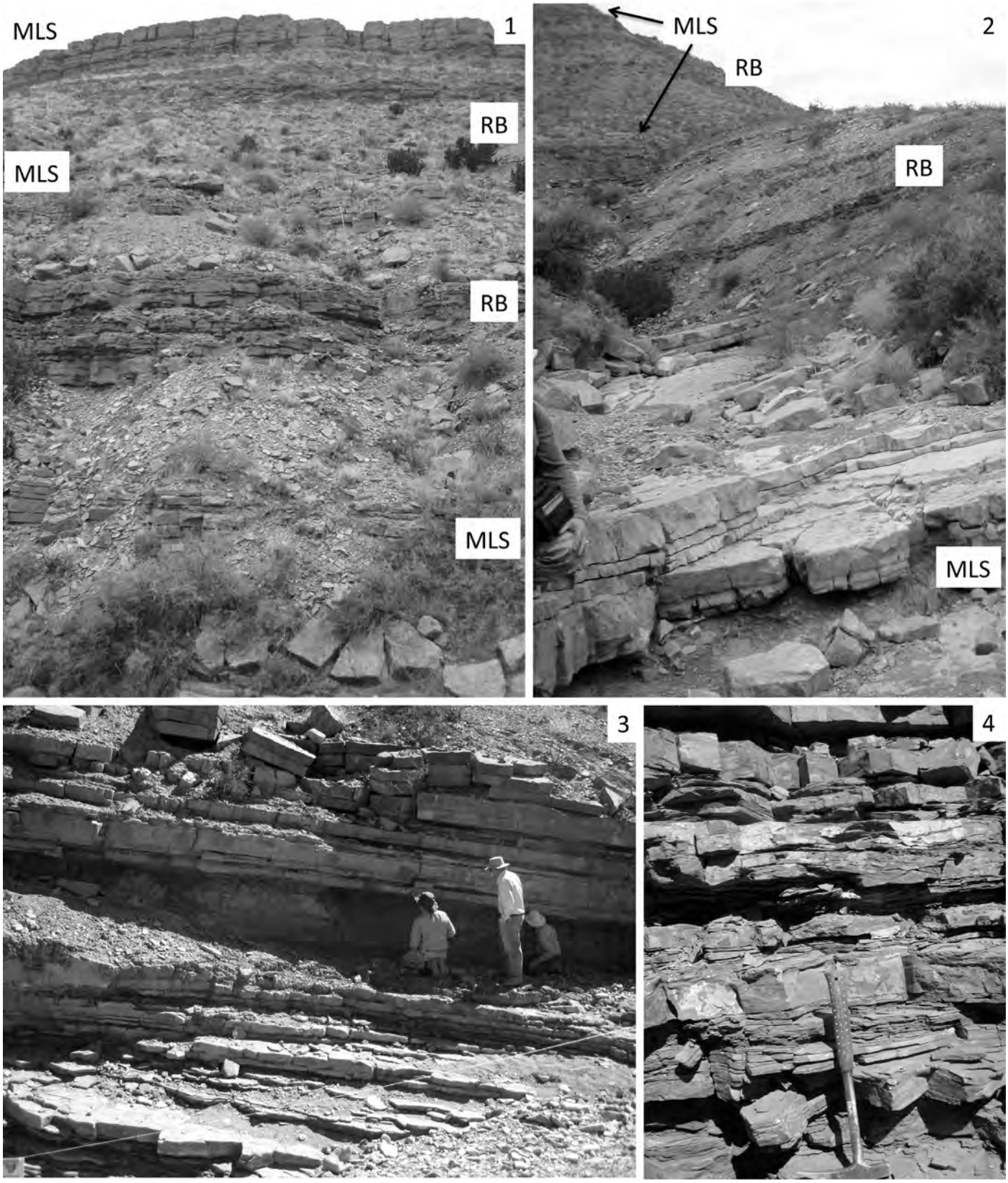


FIGURE 2. Robledo Mountains Formation geology. **2.1,** Branson Canyon, Robledo Mountains Formation, alternating marine carbonates (MLS) and siliciclastic red beds (RB). **2.2,** Branson Canyon, Robledo Mountains Formation, alternating marine carbonates (MLS) and red beds (RB). **2.3,** Branson Canyon, Robledo Mountains Formation, alternating siltstone and claystone beds. **2.4,** Branson Canyon, Robledo Mountains Formation, alternating siltstone and claystone beds; hammer is 40 cm in length.

FIGURE 3. Mat of *Walchia* branches encased in a claystone drape. Branches and branch debris lack preferential orientation and comprise multiple layers. Field photograph. Padded portion of hammer handle is 19 cm in length.

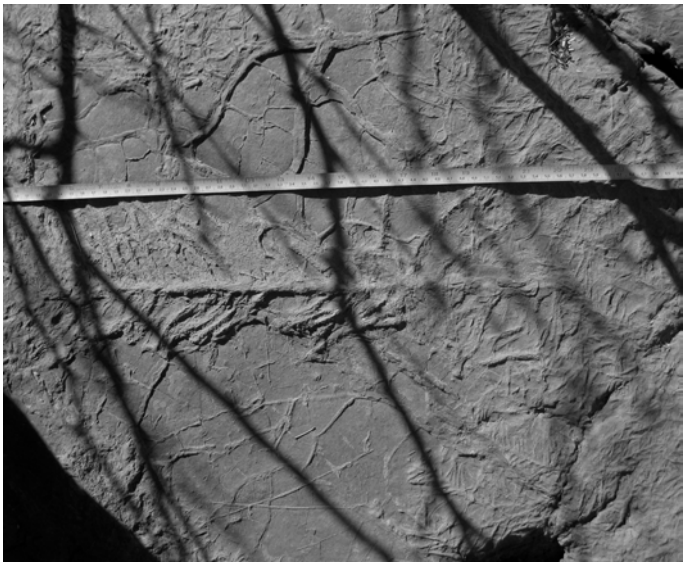


FIGURE 4. *Walchia piniformis* branch and fragmentary remains embedded in a thin claystone layer with mudcracks. Looking up from the bottom. Field photograph. Scale in centimeter and inches.

with a generally hot and dry background climate.

Paleogeographically, the PTNM lies at the southern edge of the Robledo shelf (Fig. 1), between the deeper Orogrande Basin and the Abo coastal plain (Mack et al., 1995; Lucas et al., 2012). In the Robledo Mountains, Hueco Group strata are somewhat transitional between the terrestrial Abo-Yeso strata to the north and the more marine Hueco strata of the Hueco seaway in southern and southeastern New Mexico (Krainer and Lucas, 1995). The alternation of terrestrial red beds and marine carbonates in the Robledo Mountains Formation does not mean, however, that the red bed floras grew in settings fringing the coastline. Physical proximity within a stratigraphic section is not necessarily indicative of physical proximity in space. In fact, the maturity and thickness of many of the paleosols (Mack et al, 2010) suggests long periods of development in a fluvial, floodplain setting, distant from the coastline. Plus, flatness of the landscape could permit significant variations in the marine coverage of the area with relatively minor changes in sea level. The absence or minor representation of fluvial channels in the red bed succession, combined with sheet flood deposits, may reflect the development of distal fan deposits, from which unchannelized or weakly channelized flow proceeded to the coastal regions during wetter periods. Fan deposits correlative with the Robledo Mountains Formation have been documented to the east of the PTNM in the Sacramento Mountains (Lucas et al., 2014). These thin rapidly toward the Hueco seaway, where they are correlative with mudstones and finer sandstones that interfinger with marine rocks. These deposits lend some credence to the possibility of sheet flood sources in nearby tectonically active areas. Such a scenario could account for Abo/Robledo Mountain sheet flood deposits more parsimoniously than crevasse splays from unidentified fluvial channels on the coastal plain (Mack et al., 2010; Voigt et al. 2013).

FOSSIL-PLANT COLLECTIONS

Fossil plants from the Robledo Mountains Formation were collected in eight geographically distinct sites in the PTNM. At a number of these sites, the exposures were areally widespread enough that several sub-collections were made. The informal names applied to these sites, and the collection numbers are listed below (NMMNH-New Mexico Museum of Natural History, USNM-National Museum of Natural History). Exact sites of these areas are on file at the respective museums.

(1) Community Pit: NMMNH 8220, USNM43564
(2) Apache Canyon: USNM43557, USNM43558, USNM43559, USNM43560, USNM43561
(3) Mouth of Apache Canyon: USNM43556
(4) Tributary of Apache Canyon: USNM43555
(5) Discovery Site: USNM43565
(6) Branson Canyon: USNM43575, USNM43576, USNM43577
(7) Apache Dam: USNM43553
(8) Triangle Intersection: USNM43562

The collections, in all cases other than that described by Voigt et al. (2013), are what may be described as "surface collections" – obtained largely from outcrop but with little or no excavation. Even though the plant remains are concentrated in finer grained layers of the siltstone-claystone facies, the rocks are highly indurated and not conducive to excavation with hand tools. Plants are located by surface prospecting to find bedding-plane exposures of sufficient extent that fossiliferous content is revealed. Minor working with hand tools was necessary to extract particular specimens. In many instances, however, plant remains could not be removed from the outcrop surfaces and only photographic documentation was possible (e.g., Fig. 5). Only in exceptional instances, where no fossils in place could be found, were collections made from loose pieces, so-called "float," that could not be connected directly with any particular in situ bed.

RED-BEDS FOSSIL FLORA, PTNM

The fossil flora from the red beds in the PTNM is of low diversity and generally the same from one collecting site to another, with exceptions. In addition, it is closely similar to that found in the Abo Formation in the central and northern parts of New Mexico, wherein there is no proximity to marine conditions (Hunt, 1983; DiMichele et al., 2007, 2013a). The flora is overwhelmingly dominated by the walchian conifer *Walchia piniformis* Sternberg, with some specimens possibly of *Otovicia* (*Walchia*) *hypnoides* (Brongniart) Kerp et al. and a variety of unattributable morphologies. There are minor occurrences of other plants including *Supaia* cf. *thinnfeldioides* White, *Taeniopteris* Brongniart, callipterids, perhaps attributable to *Rhachiphyllum schenckii* Kerp, and an undescribed gigantopterid with venation intermediate between *Gigantopteridium* Koidzumi and *Cathaysiopteris* Koidzumi. There also are rare fragments of fern-like foliage, roots, seeds and polliniferous organs.

Description of a flora from the PTNM is presented in Voigt et al. (2013), from the Community Pit site. Plant fossils, principally conifers, are mentioned in Lucas et al. (1995), Braddy (1998) and DiMichele et al. (2013a), among others. Below we briefly describe the main floral elements of that assemblage specific to the Robledo Mountains red-bed facies, interlayered siltstone-claystone.

FIGURE 5. *Walchia piniformis* branches in a claystone layer above a thicker layer of siltstone. Branches show no preferential orientation. Field photograph. Hammer is 28 cm in length.

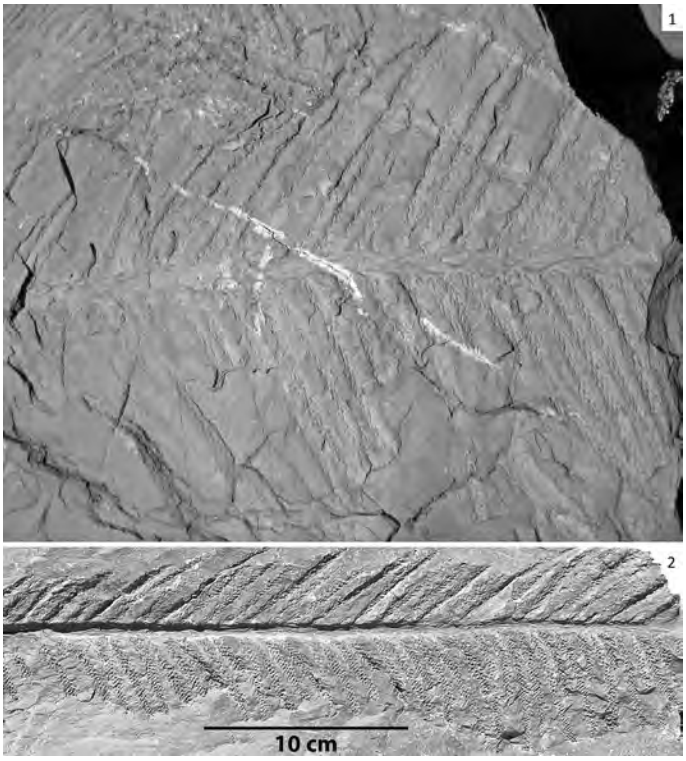


FIGURE 6. *Walchia piniformis*. **6.1**, Large branch showing planate form, typical needle-like, spreading leaves. Discovery Site. Field photograph. USNM locality 43565. **6.2**, Large branch mold, showing planate form and arrangement of foliage. This specimen was found oriented at right angles to bedding in a siltstone, indicating rapid burial and considerable stiffness (possibly due to drying) of the specimen at the time of burial. Insect Hill subsite, Apache Canyon, USNM Specimen 558251, USNM locality 43557. Scale bar = 10 cm.

Walchian Conifers

Walchian conifers are the most abundant plants in the PTNM red-bed floras. It could be stated confidently that they are the overwhelmingly dominant elements of these floras. We assign the most commonly encountered morphotype to *Walchia piniformis*, though the fit with that species is not exact. This form also bears similarity to Morphotype IVA of Looy and Duijnstee (2013), from younger Permian strata in the north-central Texas redbeds. The Robledo Mountains Formation form is characterized by plagotropic branches (Figs. 3-6) of lengths approaching 50 cm. The bases of some branches are consistent with a deciduous-branch habit of the parental tree (Fig. 4) (Looy, 2013). The branches bear elongate, narrow, upturned, acuminate, scoop-like leaves that are not closely adpressed to the parent axis (Fig. 6.2, see also Voigt et al., 2013, their figure 8H). There are less common specimens with small, triangular, adpressed leaves, borne on plagiotropic branches. Such specimens are usually preserved as three-dimensional casts or molds (Figs. 7.2-7.4), which can make their leaves appear to be more adpressed than is, in fact, the case. And some specimens appear to have intermediate morphologies (see Fig. 7.1 – some leaves appear adpressed and others are free and ascendant – at white arrows). These small-leaved forms may be compared with *Otovicia hypnoides* (Kerp et al., 1990), but likely are distinct from that species (Fig. 7). They also bear some similarity to Morphotype II of Looy and Duijnstee (2013). Other kinds of conifer remains are encountered rarely and are likely morphological variants of these two more commonly encountered forms.

Supaia thinnfeldioides

Specimens assignable to *Supaia thinnfeldioides* were found at several sites, but always as isolated, poorly preserved elements (Fig. 8.1). *S. thinnfeldioides* occurs at many other locations in the Abo Formation red beds, often in great abundance (e.g., DiMichele et al., 2007). In the Abo Formation walchian conifers and *Supaia* do not occur together in equal proportions. Generally they are found in completely distinct populations or co-occur as minor elements of the biomass in assemblages dominated by the other form.. It is probable that *Supaia* is a peltasperm (Wang, 1997, 2005). An occurrence elsewhere in the Abo Formation of upright stems in association with *Supaia* foliage suggests a small tree or shrub stature and opportunistic life history, colonizing disturbed sites and living in areas subject to disturbance (DiMichele et al., 2012).

Callipterids

There is only a single specimen reported from the PTNM red beds attributable to the callipterids, a group of peltaspermous seed plants (Kerp, 1988). This specimen, described and illustrated by Voigt et al. (2013, their figure 8I) as callipterid foliage of uncertain affinity is reillustrated here as Figure 8.2. We have found no additional specimens during our collecting and prospecting in the PTNM red beds.

The callipterid identification of Voigt et al. (2013) is consistent with the presence of rachial pinnules and the high-angle venation of the laminate segments. The specimen most closely resembles the genus *Rhachiphyllum* Kerp. This genus is typified by pinnules/laminate portions of the frond that are of flat aspect, have steeply ascending lateral veins, and relatively weakly developed midribs that are superficial on the lamina. In these features, it contrasts sharply with the somewhat similar form *Autunia* Krasser emend Kerp, which also has steeply ascending lateral venation, but in which the pinnule lamina is vaulted, resulting in a sunken, well delimited midvein in the pinnules (Kerp , 1988). *Rhachiphyllum* has not been found in connection or in a statistically demonstrable association with callipterid reproductive organs so, at this time, its peltaspermacean affinity is conjectural, but seems highly likely.

Callipterids are significant components of Early Permian floras throughout Europe (Kerp and Fichter, 1985; Opluštil, 2013) and in the Texas and Oklahoma portions of the southwestern United States (Chaney and DiMichele, 2007; DiMichele et al., 2013b; Tabor et al., 2013). They are not, however, a significant component of Early Permian red-bed floras of the Abo Formation and its correlatives in New Mexico (DiMichele et al., 2013a). Callipterids, particularly *Autunia conferta* (Sternberg) Kerp, are present in these floras, but are rare and have not been found to be abundant at any particular site where they are known to occur. Elsewhere in the PTNM, in the stratigraphically lower Community Pit Formation of the Hueco Group, a flora containing the callipterid *Lodevia oxydata* (Goeppert) Kerp has been found in a channel filled with brackish-water limestone, possibly formed during a period of strongly seasonally dry to xeric conditions (Falcon-Lang et al., this volume; DiMichele et al., this volume). These occurrences, the rarity of callipterids in the red beds, and the extremely unusual occurrence of *Lodevia oxydata* in abundance but in a rarely

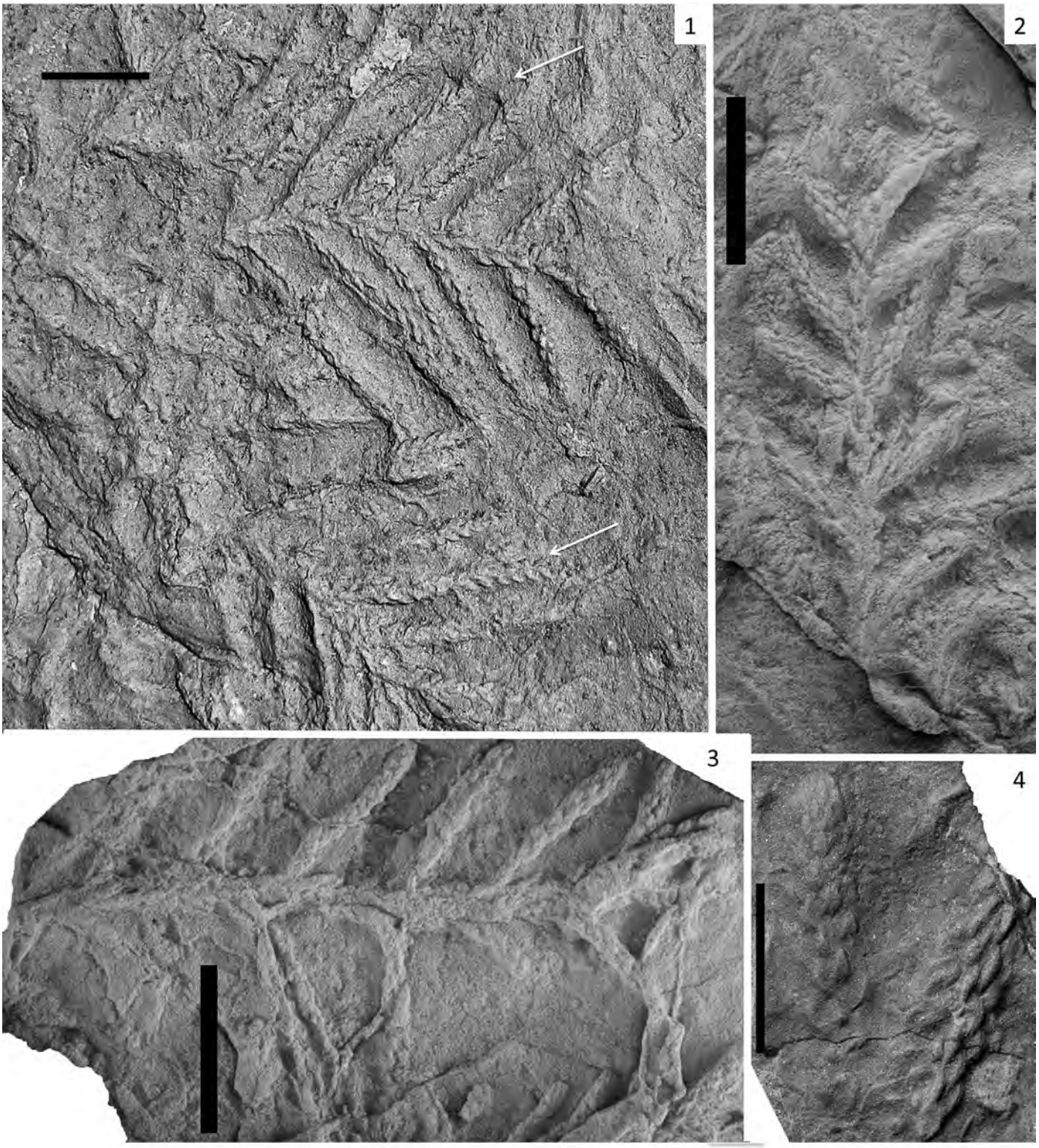


FIGURE 7. cf. *Otovicia hypnoides*. All of these specimens may, in fact, be morphological variants of *Walchia piniformis*. All are characterized my small, triangular, seemingly adpressed leaves (but note specimen illustrated in image 7.1). **7.1**, Branches with variation in foliage morphology ranging between that typical of *W. piniformis* (white arrows) and *O. hypnoides*. Apache Canyon, Field photograph, USNM locality 43559. **7.2**, Very small branch. Apache Canyon, USNM Specimen 596867, USNM locality 43560. **7.3**, Very small branch. Mouth of Apache Canyon, USNM specimen 596872, USNM locality 43556. **7.4**, Branch tip casts. Apache Canyon, USNM Specimen 596869, USNM locality 43560. All scale bars = 1 cm.

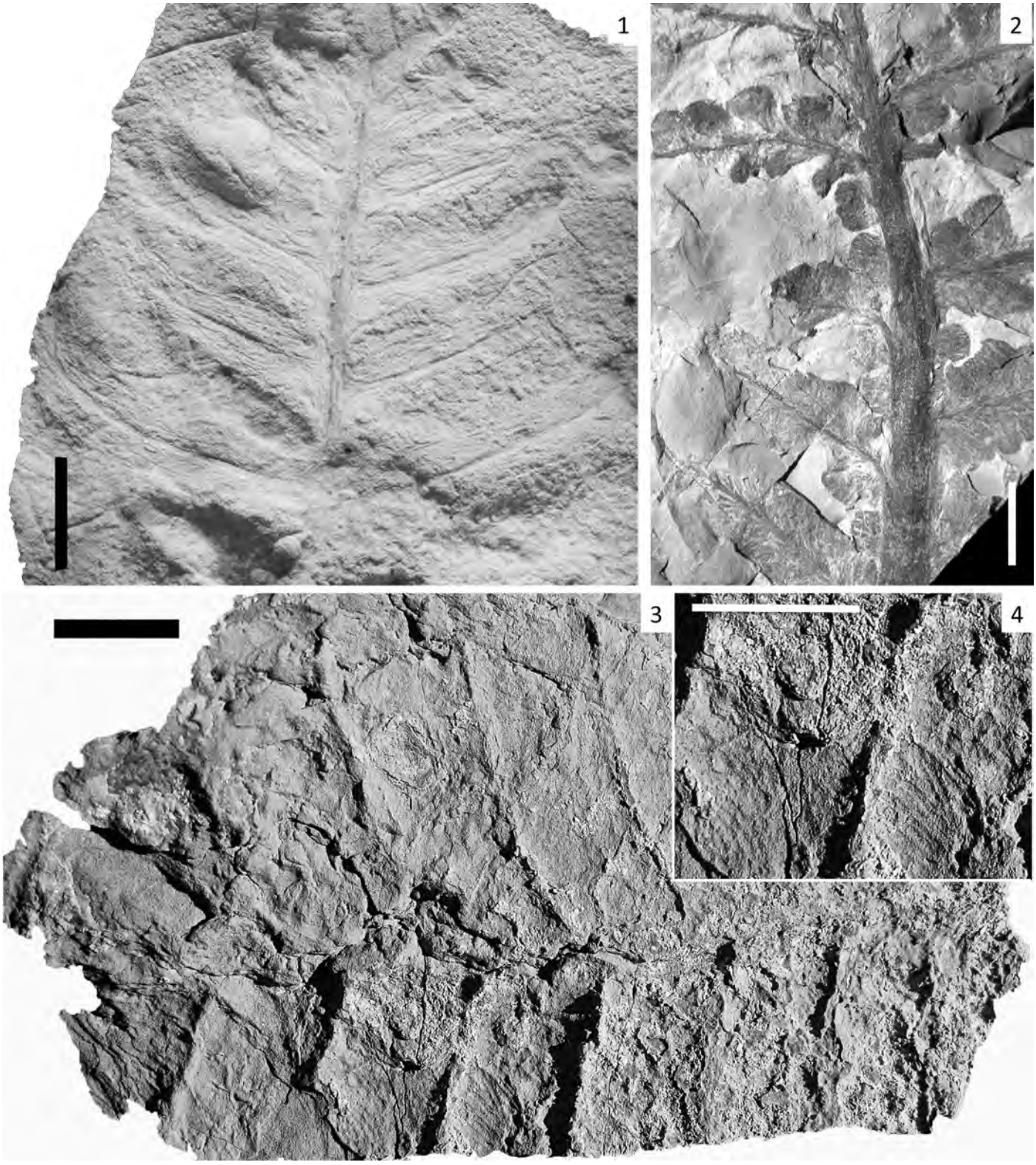


FIGURE 8. Peltasperms. **9.1**, *Supaia thinnfeldioides* with thick lamina obscuring secondary veins. Apache Dam, USNM Specimen 596870, USNM locality 43553. **9.2**, Callipterid, cf. *Rhachiphyllum*. Voigt et al. (2013) Figure 8I. Community Pit, NMMNHS Specimen number NMMNH P-62610. NMMNH locality 8220. **9.3**, *Gigantopteridium*, form with venation intermediate between *Gigantopteridium* and *Cathaysiopteris*. Triangle Intersection, USNM Specimen 558281, USNM locality 43562. **9.4**, Detail of venation in specimen illustrated in 9.3. All scale bars = 1 cm.

encountered depositional setting, indicate that callipterids were part of the Early Permian landscape in western Pangea, but were, for various taphonomic reasons, typically not preserved in the fossil record.

Gigantopterids

Several gigantopterid specimens were found at the Triangle Intersection locality. This is the only occurrence of gigantopterids that we have encountered in any Abo Formation or equivalent red-bed deposits in the course of fieldwork. Similarly, we have not identified gigantopterids in either the NMNH or NMMNH collections from any Abo Formation or equivalent strata. Read and Mamay (1964) report an occurrence of a single fragmentary specimen of "*Gigantopteris"*, presumably *Gigantopteridium*, from the Abo Formation near Orogrande, NM, which is in the environs of Alamogordo, and thus, like the PTNM occurrence, in the southern part of the state and Abo outcrop belt. We could not locate any evidence of the specimen in the USNM collections from this site.

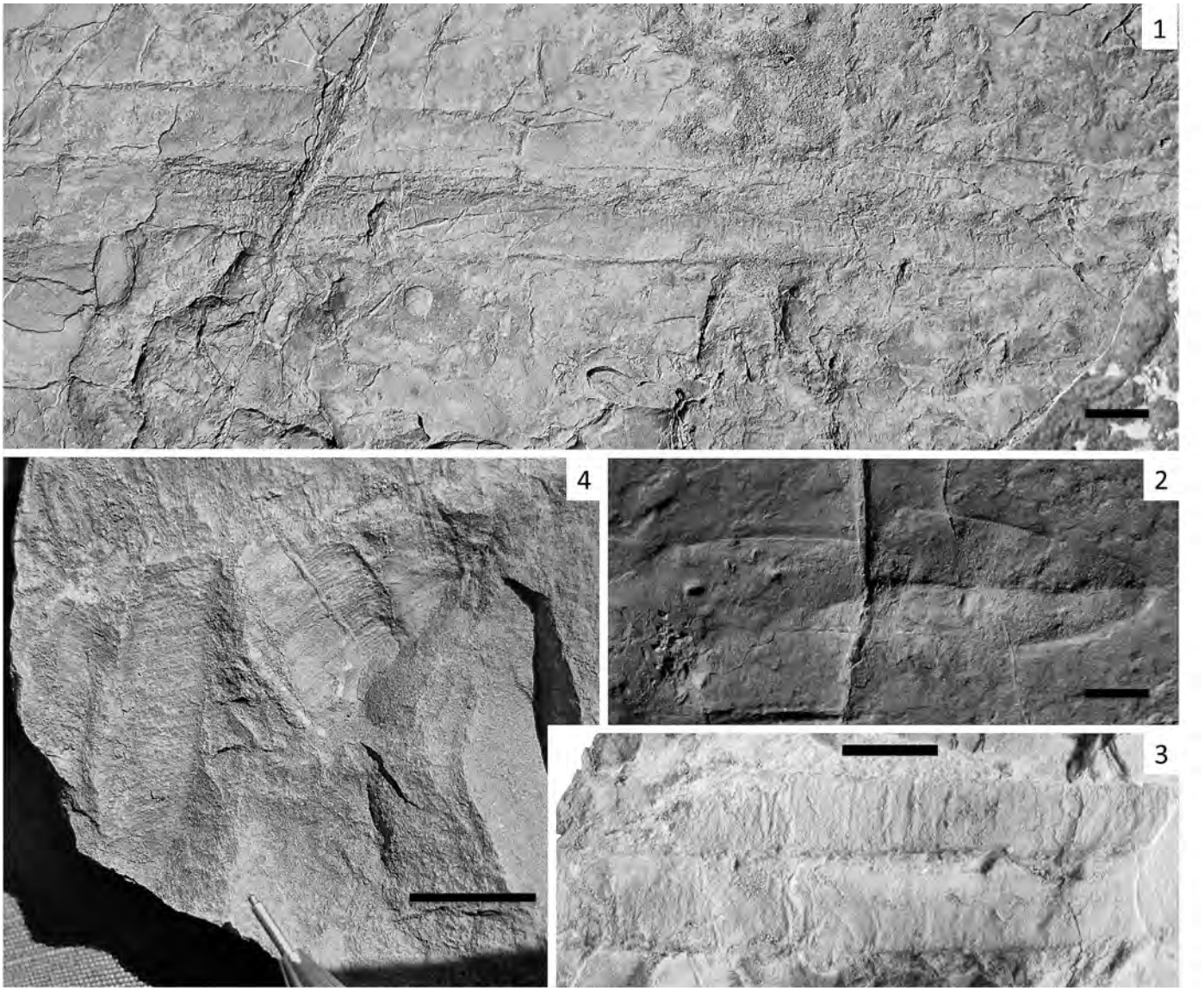
The gigantopterid specimens from the PTNM are poorly preserved in sandstone (Figure 8.3), a lithology in which gigantopterids are commonly preserved, particularly the earliest occurring North American genera *Gigantopteridium* and *Cathaysiopteris*. The PTNM specimens most closely resemble *Gigantopteridium*, but particularly an undescribed form that is somewhat intermediate in its morphology between *Gigantopteridium* and *Cathaysiopteris*. In this form, the tertiary venation is not as well organized into fascicles as in *Gigantopteridium*, but is somewhat more seriate, and suture veins are more prominent than in *Gigantopteridium*, as in *Cathaysiopteris* (Fig. 8.4).

Stratigraphically, in north-central Texas, the first gigantopterids, of the *Gigantopteridium* form, appear around the horizon of the Elm Creek Limestone (Read and Mamay, 1964; Hentz, 1987). The Elm Creek traditionally marks the base of the Leonardian in the north-Texas section (using fususlinids: Myers, 1968), which, based on conodonts, is of early Artinskian age (e.g. Wardlaw, 2005). This is congruent with the age determined for the Robledo Mountains Formation based on conodonts and other marine invertebrates.

Taeniopteris

Taeniopteris is a rare element in the PTNM red-bed floras, as it is in the Abo Formation throughout New Mexico. *Taeniopteris* is not a "natural" genus and includes both ferns and what are suspected to be seed plants (Remy and Remy, 1975). Some of the larger, more robust forms have been suggested to be ancestors of cycads, or of broadly cycadophytic affinity (Mamay, 1976; Gillespie and Pfefferkorn, 1986), though more recent research has brought that interpretation into question (Axsmith et al., 2003). There are many described species of *Taeniopteris*, and the genus was widespread in the equatorial tropics during the Permian, but appears to be significantly less common in the European portions of Euramerica than in the more westerly regions (e.g., Voigt and Röβler, 2004).

The PTNM *Taeniopteris*, to the extent that can be determined from the few preserved fragments, is predominantly of one kind, a narrow, elongate form with long, tapering terminal portions (Fig. 9.1), bluntly rounded apices (Fig. 9.2), leathery texture (Fig. 9.3) and secondary venation that is seriate and makes a right angle with the midvein or may be slightly inclined toward the apex of the leaf (acroscopically) (Fig. 9.4). At one site, Mouth of Apache Canyon, high in the Robledo



Mountains Formation, *Taeniopteris* is the dominant element. Voigt et al. (2013) illustrated a fragmentary specimen with similar morphology from stratigraphically low in the formation (re-illustrated here as Fig. 9.2).

Miscellaneous Plant Remains

There are several occurrences of unattributable reproductive organs or vegetative remains in the PTNM red-bed collections. These include clusters of what appear to be sporangia of a type not found at other localities throughout the Abo Formation (Fig. 10.1). These organs were found at the Mouth of Apache Canyon locality, solely in association with *Taeniopteris* of a narrow form. Seeds are extremely rare in Abo Formation floras and this is equally true in the Robledo Mountains Formation. Voigt et al. (2013, their figure 8F) reported small, winged seeds of a walchian-conifer-type, reillustrated here as Figure 10.2. These are very similar to seeds associated with conifer cones from some Early Permian localities in north-central Texas (Chaney, personal observation) and similar seeds have been described for other walchians by Rothwell et al. (2005).

The presence of upright stems, buried in flood sediments, has rarely been reported in Abo strata and their equivalents. Voigt et al. (2013, their figure 5C) illustrate a longitudinal section through a stem of approximately 1 cm diameter from the lower Robledo Mountains Formation, reillustrated here as Figure 10.3. Mack et al. (2010) also mention, but do not illustrate, small, upright stems in association with buried paleosol surfaces, also in what can be inferred to be the Robledo Mountains Formation (they use different stratigraphic terminology). These reported stems are congruent in size and depositional setting with stems reported in association with *Supaia* foliage and tetrapod trackways from the Abo Formation in the vicinity of the Mud Springs Mountains, near Truth or Consequences, NM (DiMichele et al., 2012).

Fossil roots of fibrous character occur throughout the Robledo Mountains Formation at various locations in red-bed siltstones.

DISCUSSION

The flora of the Lower Permian red beds in PTNM is compositionally closely similar to that of the corrrelative Abo Formation found throughout the central portion of New Mexico (DiMichele et al., 2013a). The dominant elements of the flora are walchian conifers, of a form similar to *Walchia piniformis*, found most often in low diversity assemblages lacking other kinds of plants. Although present in the PTNM, the probable peltasperm *Supaia* is quite rare; elsewhere, in the Abo Formation, *Supaia* is locally abundant and dominates low diversity fossil assemblages that commonly lack conifers (e.g., DiMichele et al., 2007). The patterns of distribution and relatively rare co-occurrence of these plants suggest spatial separation of their populations on the original landscape. Other rare elements in the Robledo Mountains Formation flora, such as *Taeniopteris*, callipterids, and gigantopterids, are equally rare throughout the Abo Formation.

The PTNM red-bed floras of the Robledo Mountains Formation are of significance because they occur within a mixed marine-terrestrial stratigraphic sequence. The close proximity of marine strata has led to interpretations of the Hueco terrestrial red beds as tidal flats (e.g., Mack and James, 1986; Lucas et al., 1995; Minter et al., 2006; Minter and Braddy, 2009). This has been reassessed recently based on studies of paleosols (Mack et al., 2010) and on detailed sedimentological analysis of the terrestrial siliciclastics in combination with analysis of ichofossil assemblages, neither of which are of peritidal character (Voigt et al., 2013). These more recent studies suggest that the terrestrial red beds represent distal, coastal floodplain settings characterized by sheet-flood crevasse splays and mud-dominated overbank deposits that formed under a seasonally dry climatic regime (Mack et al., 2010). The larger scale alternation of terrestrial and marine rocks is suggestive of allogenic drivers (Mack, 2007;Mack et al., 2010), possibly Southern Hemisphere ice-volume fluctuations during the waning of Permian Glacial II in the late Artinskian (Montañez et al., 2007).

From a paleobotanical viewpoint, the Robledo Mountains Formation simply exacerbates the enigma of the low-diversity and monotonous composition of the flora of the Early Permian siliciclastic red beds. Here, in an interval characterized by interbedded marine and terrestrial strata, there are no detectable differences in the floristic composition from coeval strata to the north that experienced no detectable marine influence. The red-bed facies extends from northern New Mexico, in the Zuni Mountains, to the southern portions of the state, bordering the Hueco seaway, where interbedded red beds and carbonate rocks have been designated the Hueco Group and encompass the Robledo Mountains Formation. Throughout this vast area, the composition of the flora of the Abo Formation and equivalent strata is the closely similar (Hunt, 1983; DiMichele et al., 2007, 2013a). The dominant plants at most sites are walchian conifers, generally attributable to *Walchia piniformis*, but also to other taxa, and locally deposits may be found that are dominated by *Supaia thinnfeldioides*.

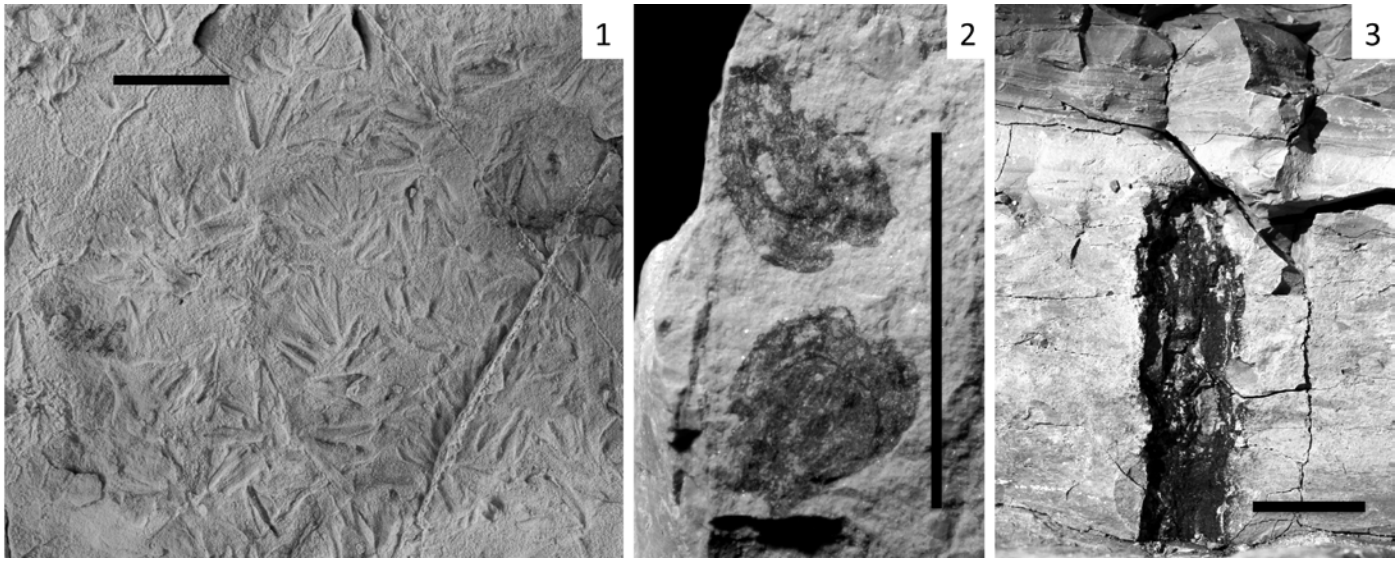


FIGURE 10. Miscellaneous. **10.1**, Suspect male reproductive organs found in association with *Taeniopteris*; Mouth of Apache Canyon, USNM Specimen 596873, USNM locality 43556. **10.2**, Winged, playspermic seeds of a form commonly found in association with conifer remains, Voigt et al. (2013) Figure 8F. Community Pit, NMMNHS Specimen number NMMNH P-62502. NMMNH locality 8220. **10.3**, Small upright stem similar to stems attributed to *Supaia* by DiMichele et al. (2012), Voigt et al. (2013, figure 5C). Community Pit. Field photograph, NMMNH locality 8220. All scale bars = 1 cm.

FIGURE 9 (facing page). *Taeniopteris*. **8.1**, General shape, elongate, gradually tapering toward the apex. Mouth of Apache Canyon, USNM Specimen 596871, USNM locality 43556. **8.2**, Blunt tip. Voigt et al. (2013) Figure 8C. Community Pit, NMMNHS Specimen number NMMNH P-62607. NMMNH locality 8220. **8.3**, Thick, probably xeromorphic lamina. Mouth of Apache Canyon, USNM Specimen 596874, USNM locality 43556. **8.4**, Secondary venation at nearly right angles to the midvein. Mouth of Apache Canyon, USNM Specimen 558417, USNM locality 43556. All scale bars = 1 cm.

Other plants clearly were part of this assemblage, indicated by scattered, rare occurrences of various taxa, nearly all seed plants of xeromorphic morphology. Yet there are other facies within the Abo Formation and correlatives. These include those composed of gray shales and sandstones (e.g., Lucas 2012a, b) that contain quite different, more diverse floras that include a significant component of lower vascular plants and medullosan seed ferns, or a unique flora preserved in limestones composed of voltzian coniferophytes and callipterids (DiMichele et al., this volume). Equivalent age floras from farther to the east, along the paleoequator, also are significantly more diverse and less dominated by conifers than the Abo red-bed floras (e.g., Chaney and DiMichele, 2007; Tabor et al., 2013). Thus, the Abo red beds stand out regionally as encompassing a peculiar plant assemblage, both in terms of diversity and composition.

There are no clearly identifiable taphonomic filters that might have created a so-called megabias (Behrensmeyer et al., 2000) in the formation of these fossil assemblages. It appears that the environments represented by the Abo red beds were indeed populated by vast forests of conifers, as suggested by the fossil assemblages. Locally, particularly in areas of disturbance, stands of small *Supaia* plants were abundant. Within this landscape there also were populations of a few other kinds of plants, particularly callipterids and taeniopterids, though nowhere have these plants been found in abundance. To date, gigantopterids have only been found in areas bordering the Hueco seaway, but the number of occurrences is so small that this cannot be taken as statistically meaningful. Ground cover plants have rarely been identified and are confined to small ferns and sphenophylls, which may suggest selective preservation of arborescent taxa. Thus, the Robledo Mountains Formation floras from the PTNM strengthen the interpretation that floras from the Early Permian New Mexico red beds are unique among known Early Permian assemblages from the Pangean equatorial regions.

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