



## ***The wood flora from the Upper Cretaceous Crevasse Canyon and McRae formations, south-central New Mexico, USA: A progress report***

Emilio Estrada-Ruiz, Joan M. Parrott, Upchurch, Garland R., Jr., Elisabeth A. Wheeler, Dori L. Thompson, Greg H. Mack, and Mindy M. Murray  
2012, pp. 503-518. <https://doi.org/10.56577/FFC-63.503>

*in:*  
*Geology of the Warm Springs Region*, Lucas, Spencer G.; McLemore, Virginia T.; Lueth, Virgil W.; Spielmann, Justin A.; Krainer, Karl, New Mexico Geological Society 63<sup>rd</sup> Annual Fall Field Conference Guidebook, 580 p.  
<https://doi.org/10.56577/FFC-63>

---

*This is one of many related papers that were included in the 2012 NMGS Fall Field Conference Guidebook.*

---

### **Annual NMGS Fall Field Conference Guidebooks**

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual [Fall Field Conference](#) that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

### **Free Downloads**

NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only *research papers* are available for download. *Road logs*, *mini-papers*, and other selected content are available only in print for recent guidebooks.

### **Copyright Information**

Publications of the New Mexico Geological Society, printed and electronic, are protected by the copyright laws of the United States. No material from the NMGS website, or printed and electronic publications, may be reprinted or redistributed without NMGS permission. Contact us for permission to reprint portions of any of our publications.

One printed copy of any materials from the NMGS website or our print and electronic publications may be made for individual use without our permission. Teachers and students may make unlimited copies for educational use. Any other use of these materials requires explicit permission.

*This page is intentionally left blank to maintain order of facing pages.*

# THE WOOD FLORA FROM THE UPPER CRETACEOUS CREVASSE CANYON AND McRAE FORMATIONS, SOUTH-CENTRAL NEW MEXICO, USA: A PROGRESS REPORT

EMILIO ESTRADA-RUIZ<sup>1</sup>, JOAN M. PARROTT<sup>1</sup>, GARLAND R. UPCHURCH, JR.<sup>1\*</sup>, ELISABETH A. WHEELER<sup>2,3</sup>,  
DORI L. THOMPSON<sup>1</sup>, GREG H. MACK<sup>4</sup> AND MINDY M. MURRAY<sup>1</sup>

<sup>1</sup>Department of Biology, Texas State University, San Marcos, TX 78666 USA; \*gu01@txstate.edu

<sup>2</sup>Department of Forest Biomaterials, North Carolina State University, Raleigh, NC, 27695

<sup>3</sup>North Carolina Museum of Natural Sciences, Raleigh, N.C., 11 West Jones Street, Raleigh, NC 27601-1029;

<sup>4</sup>Department of Geological Sciences, New Mexico State University, Las Cruces, NM, 88003

**ABSTRACT**—Over the past two decades a significant wood flora has been discovered from the Ash Canyon Member of the Crevasse Canyon Formation (Campanian) and the Jose Creek Member of the McRae Formation (Maastrichtian). To date, at least 10 types of dicots, three types of monocots, and 7 types of conifers are known from approximately 30 sectioned specimens. Woods of Celastraceae and Myrtaceae from the Jose Creek Member of the McRae Formation constitute the first occurrences of these families in the North American fossil wood record. Fossil woods and leaves show congruent patterns of relationships to modern families, but in some cases woods document families not yet validly recognized from the Cretaceous leaf record. *Metcalfeoxylon*, *Paraphyllanthoxylon*, *Platanoxylon*, *Palmoxylon*, and different types of conifer wood occur at coeval localities from northern New Mexico, west Texas, and northern Mexico, indicating that wood floras from the southern Western Interior shared a number of common elements during the Campanian–Maastrichtian. The minimal development of growth rings in all dicots and many conifers, and the occurrence of palm stems, reinforce evidence from paleosols and leaf macrofossils for warm subtropical to paratropical climates with minimal freezing and year-round precipitation.

## INTRODUCTION

The Campanian–Maastrichtian of the southern Western Interior yields a number of floras of paratropical to warm subtropical aspect (Wolfe and Upchurch, 1987b; Wolfe, 1990; Upchurch and Wolfe, 1993). Familiar occurrences of leaf and wood macrofossils include the Laramie and Denver formations of the Denver Basin (Johnson et al., 2003), the Raton and Vermejo formations of the Raton Basin (Knowlton, 1917; Ash and Tidwell, 1976), the Fruitland and Kirtland formations of the San Juan Basin (Tidwell et al., 1981; Wheeler et al., 1995; Hudson, 2006), the Aguja and Javelina formations of Big Bend, Texas (Wheeler et al., 1994; Wheeler and Lehman, 2000, 2009), and the Olmos Formation of the Sabinas Basin (Weber, 1972; Estrada-Ruiz et al., 2007, 2010, 2011). More recently, leaf and wood macrofossils have been reported from the Crevasse Canyon and McRae formations of the Cutter Sag/Love Ranch Basin (Upchurch and Mack, 1998; Bogner et al., 2007; Estrada-Ruiz et al., 2011). The Crevasse Canyon and McRae floras of southern New Mexico are noteworthy for their excellent preservation of leaf venation and wood anatomy, but they remain largely undescribed taxonomically. Permineralized woods occur abundantly in these units, and many hundreds of specimens already have been collected.

Over the past two years we have initiated a major study of the anatomy of angiosperm and conifer woods from the Crevasse Canyon and McRae formations of south-central New Mexico. To date, at least 20 different types of wood (≈species) have been recognized from approximately 30 thin-sectioned specimens, indicating that further study should produce a diverse and potentially significant flora. Here we informally describe and illustrate important wood types from the Ash Canyon Member of the Crevasse Canyon Formation and the Jose Creek Member of the McRae Formation, and discuss their floristic and paleoclimatic

significance. Woods from other units in the Crevasse Canyon and McRae formations have been discovered recently, and will be the topic of future papers.

## GEOLOGIC SETTING

The fossil woods reported here were collected by G. Upchurch, G. Mack and student co-workers in 1991, 1992, 1993, and 1998 from the Campanian–Maastrichtian of south-central New Mexico, along the northeastern flank of the Caballo Mountains and in the adjacent Cutter Sag (Fig. 1). Materials were collected from a single horizon in the Ash Canyon Member of the Crevasse Canyon Formation and from multiple horizons in the Jose Creek Member of the McRae Formation. Both represent fluvial deposition at least 200 km upstream from the shoreline of the Western Interior Seaway (Molenaar, 1983; Roberts and Kirschbaum, 1995). Together with certain assemblages known from the Campanian Aguja and Maastrichtian Javelina formations of Big Bend, Texas, they represent some of the few known Late Cretaceous wood floras from North America that are well removed from the Western Interior or Tethys seaways.

The Ash Canyon Member is dated as Campanian, based on palynomorphs known from the lower member of the Crevasse Canyon Formation (Seager and Mack, 2003) and on its angular-unconformable upper contact with the McRae Formation (Fig. 1). The Jose Creek Member of the McRae Formation is tentatively dated as early to middle Maastrichtian, based on the species composition of its megafloora (especially conifers) (Upchurch and Mack, 1998) and on its conformable contact with the overlying Hall Lake Member, which contains late Maastrichtian (Lancian) dinosaur fossils in its lower part (Lozinsky et al., 1984; Gillette et al., 1986; Wolberg et al., 1986; Lucas et al., 1998). No palynomorphs or dateable minerals have yet been recovered from either

the Ash Canyon Member or Jose Creek Member, which makes age determinations somewhat tentative.

**METHODS OF STUDY**

The fossil woods described in this paper were found as both *in situ* trunks and float. Two types of dicots, *Metcalfexylon* and *Paraphyllanthoxylon*, were collected from a fossil forest horizon in the Ash Canyon Member of the Crevasse Canyon Formation (Fig. 1). *Metcalfexylon* was found *in situ*, represented by three stumps rooted in the Bt horizon of an argillic paleosol, and clusters of wood fragments suggestive of three additional stumps.

The *in situ* stumps (now destroyed by looters) measured 0.4 to 0.75 m in diameter at the top of the buttress roots (Upchurch et al., 2003; Estrada-Ruiz et al., 2012). *Paraphyllanthoxylon* was collected as float in association with fragments of *Metcalfexylon* and conifer wood.

Multiple species of dicots, monocots, and conifers were collected from *in situ* stumps and float in the Jose Creek Member of the McRae Formation. The *in situ* stumps were found in the argillic horizon of a paleosol in the Fossil Forest Section, located 73 m above the base of the Jose Creek Member (Buck and Mack, 1995; Seager and Mack, 2003). The float materials were collected from the Fossil Forest Section immediately below the fossil forest horizon, and from additional stratigraphic sections where the overlying Hall Lake Member of the McRae Formation and younger strata were absent. This minimized the odds of younger material eroding into regions with older exposed strata.

Fossil woods were cut into small blocks and sectioned. For dicots and conifers, transverse, radial, and tangential sections were cut. For monocots, only transverse and tangential sections were cut. All samples were prepared by gluing the blocks to glass slides, cutting sections, and grinding the mounted samples until the details of internal anatomy were fully visible (Haas and Rowe, 1999). Cover slips were affixed to slides using Norland Optical Adhesive Type 72 that was polymerized for at least 20 minutes using a sunlamp. Thin sections were observed with a Zeiss Photomicroscope I using brightfield optics, and photographed with a Canon Eos Digital Rebel XSi camera (12 megapixels resolution).

We present a few wood anatomical terms because the terminology of fossil wood anatomy is unfamiliar to many geologists. One important character in wood identification is the type of water-conducting element. A **tracheid** is an elongate cell with closed ends that has **pits** (small breaks in the cell walls) on its lateral walls and overlapping end walls (e.g., Fig. 7D), while a **vessel element** is an open-ended cell that has pits on its lateral walls and **perforations** (holes) on its end walls (e.g., Fig. 2C, arrow, Fig. 2D, V). Vessel elements are connected end-to-end to form **vessels**. Vessel element perforations can be **simple**, consisting of a single large opening (Fig. 5F, arrows), or **scalariform**, consisting of multiple elongate and parallel openings (Fig. 2C). The wood of all conifers is characterized by longitudinal tracheids, which constitute approximately 90 percent of the wood volume and give the wood a uniform appearance in cross section (Figs. 7A, 7E, 8A, 8D). In contrast, the wood of nearly all angiosperms is characterized by relatively wide vessel elements and narrower fibers, which give the wood a variable appearance in cross section (e.g., Figs. 2B, 3F, 4A, 4D).

A second important set of characters in wood identification is the arrangement of the storage tissue, or **parenchyma**. Parenchyma in nearly all wood is organized into radial sheets of tissue termed **rays** (e.g., Figs. 3B, 3C, R). Rays, as viewed in transverse or tangential section, can be **uniseriate**, or one cell wide (Fig. 8E), **biseriate**, or two cells wide, and **multiseriate**, or 3 or more cells wide (Figs. 3C and 4B, R). The wood of conifers typically has only uniseriate and biseriate rays, while the wood of angiosperms typically has a mix of uniseriate and multiseriate rays. In many woods there is additional parenchyma that is oriented lon-

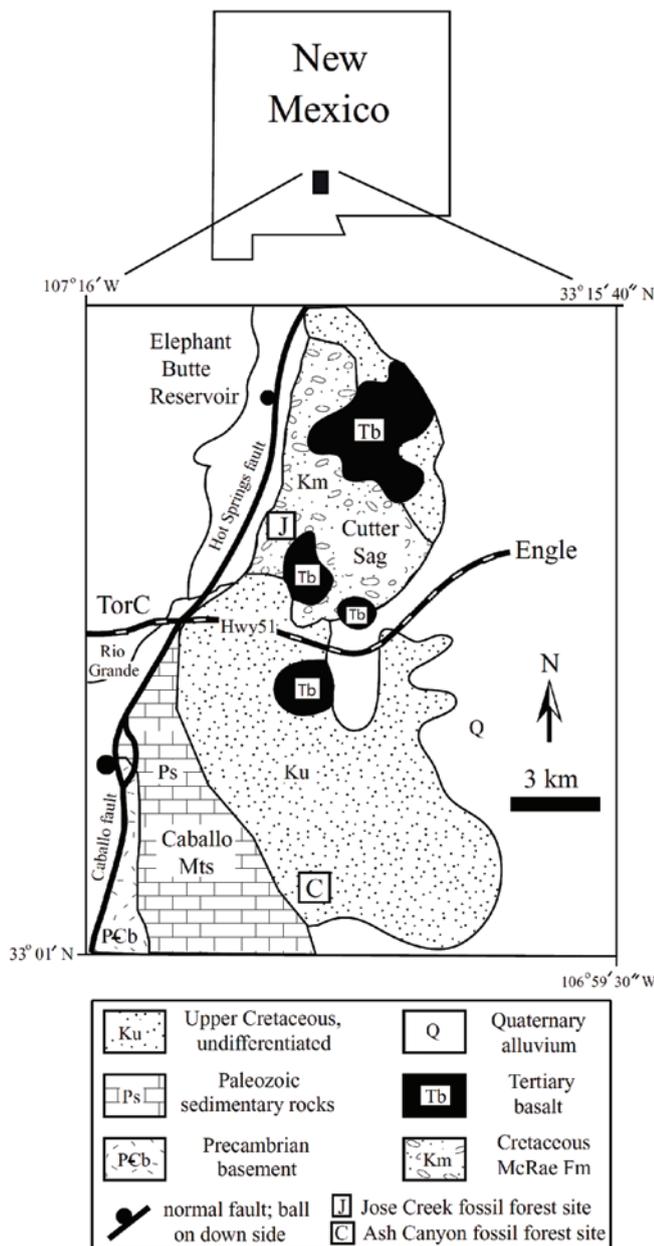


FIGURE 1. Maps showing the location and geology of the study area south-central, New Mexico, USA.

gitudinally (parallel to the long axis of the conducting elements). This is termed **axial parenchyma** (e.g., Fig. 8D, dark cells).

Many other anatomical characters are important in wood identification, including the pits between water-conducting cells and rays. These terms are discussed and illustrated in any basic plant anatomy text, such as that of Evert (2006). For dicot woods, the details of terminology follow the recommendations of the IAWA Committee (1989), and these terms are explained in the links section of the InsideWood web site (<http://insidewood.lib.ncsu.edu>) (Wheeler, 2011). For conifer woods, details of terminology follow the IAWA Committee (2004) and Philippe and Bamford (2008).

None of the woods illustrated in this paper can be placed confidently within an extant genus, and many cannot be placed confidently within an extant family. For angiosperms, we place our woods systematically using the APG (Angiosperm Phylogeny Group) phylogenetic classification of families, orders, and higher level taxa. The APG system is based on DNA sequences from multiple genes and other molecular characters (APG, 2009; Stevens, 2001-onwards). In the APG system the familiar group known as “dicots” is broken up into three groups: eudicots (most of dicot diversity), magnoliids (magnolias, laurels, and their relatives), and basal lineages (not relevant here). Monocots are retained as a separate lineage. The relationships of fossil angiosperm woods to modern taxa were determined by consulting published literature (e.g., Metcalfe and Chalk, 1950; Détienne and Jacquet, 1983; Ilic 1987, 1991; Tomlinson et al., 2011) and searching the online database InsideWood (InsideWood, 2004-onwards; Wheeler, 2011), which provides extensive coverage of “dicots”.

The woods of conifers were treated differently than those of angiosperms. This is because the nomenclature and classification of fossil conifer woods are problematic and in a state of flux. We assigned our woods to the informal anatomical groups recognized by Wheeler and Lehman (2005) pending comprehensive revision of Cretaceous conifer wood taxonomy.

The fossil woods are housed in the paleobotanical collections of Texas State University, San Marcos. Individual pieces of wood are given a specimen number preceded by the abbreviation TXSTATE. The slide number used for each illustration is given in the figure captions preceded by “S”.

## DESCRIPTION OF WOODS

### Angiosperms, Eudicots and Magnoliids

#### Ash Canyon Member, Crevasse Canyon Formation (Campanian)

Two types of angiosperm wood are known from the fossil forest horizon of the Ash Canyon Member. Eudicot woods belong to *Metcalfeoxylon*, a common genus from the Western Interior Cretaceous, while probable magnoliid wood belongs to *Paraphyllanthoxylon*, another widely known genus (e.g., Wheeler et al., 1995; Wheeler and Lehman, 2000; Estrada-Ruiz et al., 2012).

All *in situ* specimens belong to *Metcalfeoxylon kirtlandense* (Fig. 2A). Diagnostic features include large and solitary vessels,

indistinct growth rings (Fig. 2B), scalariform perforation plates (Fig. 2C, arrow), and vessel-ray parenchyma pits of similar size as the intervessel pits. The parenchyma (storage tissue) is abundant and consists of both axial parenchyma (Fig. 2B) and multiseriate rays with long uniseriate tails (Fig. 2D) (Wheeler et al., 1995). *Metcalfeoxylon* has been described from Campanian–Maastrichtian localities of the Kirtland Formation, Aguja Formation, and Olmos Formation. Although *Metcalfeoxylon* was suggested to be in the order Malvales by Upchurch et al. (2003), its affinities may actually be with the order Malpighiales (Wheeler, work in progress). Our specimens consist of three stumps in growth position and three clusters of wood fragments from the same bedding plane that probably represent the remains of three additional stumps. The *in situ* stumps measure 0.4 to 0.75 m in diameter at the top of the buttress roots (Fig. 2A). *In situ* stumps of *Metcalfeoxylon* from the Aguja Formation measure up to 1.3 m in diameter (Lehman and Wheeler, 2001).

A single specimen of *Paraphyllanthoxylon anzasii* is known as float in association with *Metcalfeoxylon* stumps (Estrada-Ruiz et al., 2012). Diagnostic features of *P. anzasii* include indistinct growth rings, vessels that are both solitary and in short radial multiples (groups), simple perforation plates, alternate intervessel pits, vessel-ray parenchyma pits with reduced borders, and common tyloses (ingrowths of parenchyma tissue that plug the vessels when they become non-functional). The rays are heterocellular (that is, with two types of cells), and the fibers consist of a mix of septate and non-septate fibers. *Paraphyllanthoxylon anzasii* has been described from the Cretaceous of Texas and New Mexico, and other species of *Paraphyllanthoxylon* have been described from Arizona, Alabama, Maryland, Texas, Europe and Asia (e.g., Cahoon, 1972; Herendeen, 1991; Wheeler et al. 1995; Meijer, 2000; Wheeler and Lehman 2000; Takahashi and Suzuki, 2003; Gryc et al., 2009). Although *Paraphyllanthoxylon* does not have the oil cells needed to definitively place it within Lauraceae, *P. anzasii* probably represents Lauraceae. This is because wood with *Paraphyllanthoxylon* anatomy has been found in an axis attached to a fossil lauraceous fruit, and Lauraceae are abundant in the Cretaceous leaf macrofossil and dispersed cuticle records, just like *Paraphyllanthoxylon* is abundant in the wood record (Estrada-Ruiz et al., 2012, and references therein). The Crevasse Canyon *Paraphyllanthoxylon* represents an axis at least 14 cm in diameter, indicating that the parent plant was a small tree or larger, depending on whether the specimen represents trunk wood or branch wood.

#### Jose Creek Member, McRae Formation (Maastrichtian)

Nine types of eudicots and magnoliids are known from the Jose Creek Member of the McRae Formation. The eudicots can be related to the extant families Platanaceae (sycamore family), Celastraceae (bittersweet family), and Myrtaceae (myrtle family), and the orders Ericales and Malpighiales. The one magnoliid illustrated in this paper represents a taxon of unclear relationship to any extant family but shows its closest similarity to Annonaceae (custard apple family).

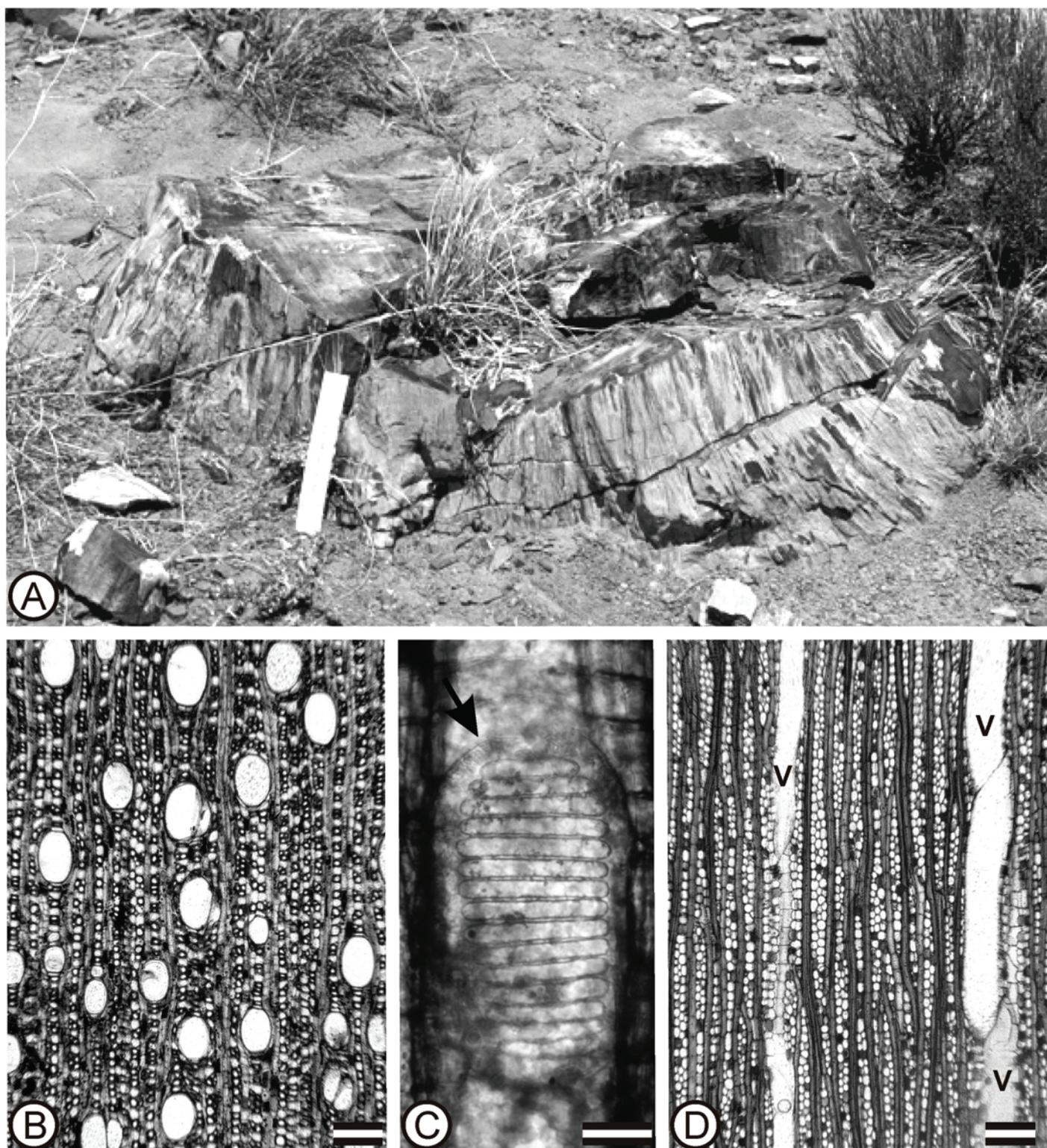


FIGURE 2. *Metcalfeoxylon kirtlandense*. **A**, *Metcalfeoxylon* stump in growth position. Scale is 15 cm long. **B**, Transverse section (TS) Solitary vessels and axial parenchyma. TXSTATE 1206-S1. Scale = 200  $\mu$ m. **C**, Radial longitudinal section (RLS). Scalariform perforation plate (arrow). TXSTATE 1206-S4. Scale = 50  $\mu$ m. **D**, Tangential longitudinal section (TLS) Rays mostly two cells wide, and vessels (V) without tyloses. TXSTATE 1206-S2. Scale = 200  $\mu$ m.

Probable Platanaceae are represented by two types of wood belonging to *Platanoxylon* (Figs. 3A–B, F, G), a genus with features characteristic of extant Platanaceae. Extant Platanaceae are

represented by a single genus, *Platanus*, with 8 species that typically grow along the margins of streams and lakes. Cretaceous Platanaceae, however, were significantly more diverse than extant

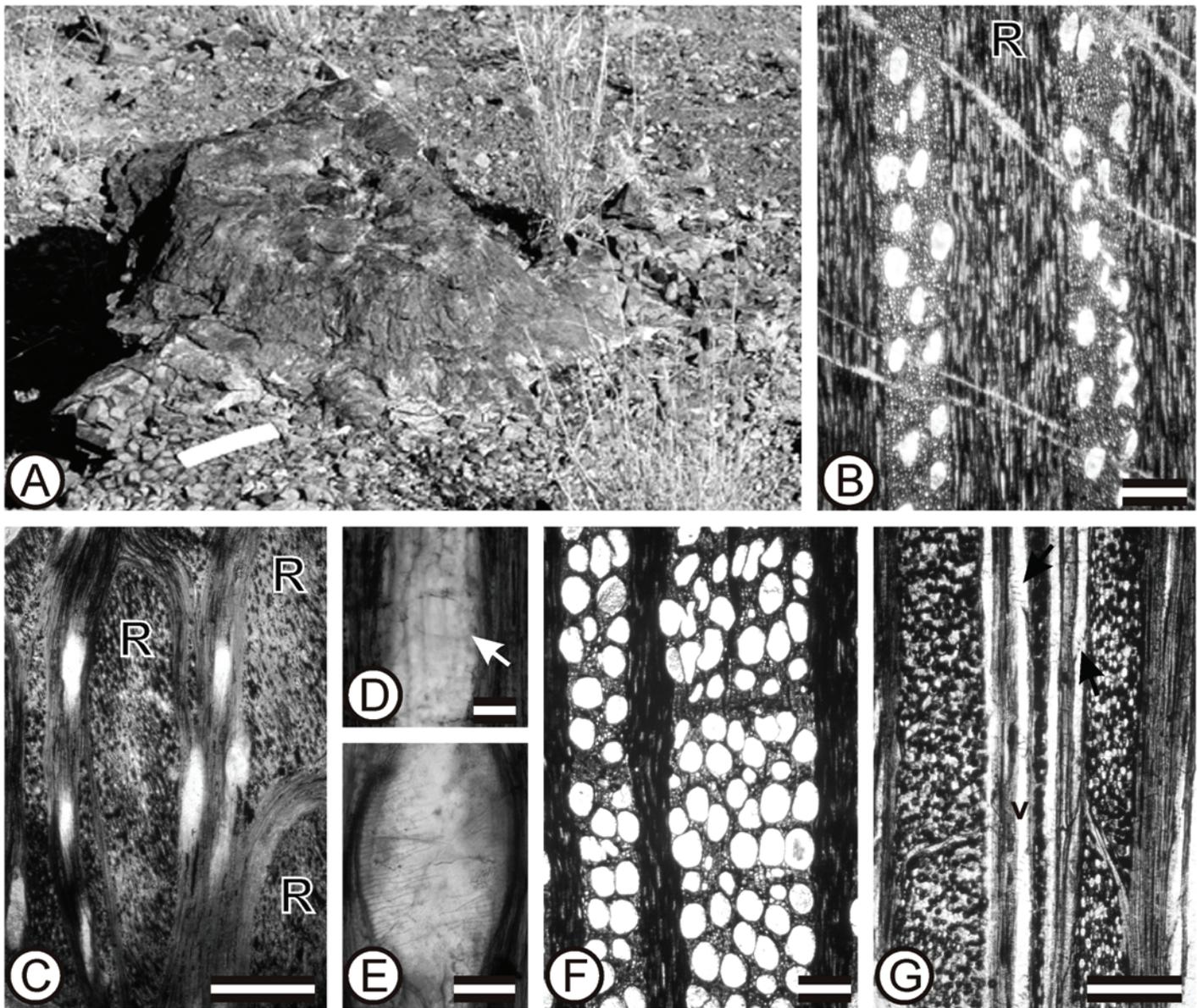


FIGURE 3. *Platanoxylon*. A–E, *Platanoxylon* sp. 2. A, Stump in growth position. TXSTATE 1212. Scale is 15 cm long. B, (TS) Solitary vessels and wide rays (R). TXSTATE 1212–S1. Scale = 200  $\mu\text{m}$ . C, (TLS) Wide rays (R). TXSTATE 1212–S3. Scale = 350  $\mu\text{m}$ . D, (RLS) Simple perforation plate (arrow). TXSTATE 1212–S11. Scale = 50  $\mu\text{m}$ . E, (RLS) Scalariform perforation plate. TXSTATE 1212–S11. Scale = 40  $\mu\text{m}$ . F–G, *Platanoxylon* sp. 1. F, (TS). Vessels solitary and in multiples. TXSTATE 1203–S1. Scale = 190  $\mu\text{m}$ . G, (TLS), Wide rays and vessels (V) with scalariform perforation plate (arrows). TXSTATE 1203–S3. Scale = 336  $\mu\text{m}$ .

Platanaceae. *Platanoxylon* sp. 2 (Figs. 3A–E) is known from an *in situ* stump that measures 40 cm at the top of the buttress roots (Fig. 3A). Diagnostic features include indistinct growth rings, diffuse porous wood (Fig. 3B), mostly solitary vessels (Fig. 3B), predominantly scalariform perforation plates (Fig. 3E) intermixed with some simple perforation plates (Fig. 3D), and small vessel-ray parenchyma pits with slightly reduced borders. The rays are homocellular (that is, with only one cell type) and exclusively multiseriate (Fig. 3C). *Platanoxylon* sp. 1 (referred to as *Platanoxylon* sp. by Estrada-Ruiz et al., 2012) differs in having a more even mixture of solitary and tangential multiples of vessels (Fig. 3F) and exclusively scalariform perforation plates (Fig. 3G, arrows). Features of the Jose Creek fossils characteristic of extant

Platanaceae and the fossil genus *Platanoxylon* include narrow and solitary vessels, scalariform and simple perforation plates, opposite to scalariform intervessel pits, wide homocellular rays with procumbent (horizontally oriented) cells, and rare or absent uniseriate rays (Wheeler et al., 1995; Wheeler and Lehman, 2009). North American occurrences of *Platanoxylon* include the Panoche Formation of California, the Kirtland Formation of New Mexico, and the Aguja Formation of Big Bend National Park, Texas (Page, 1968; Wheeler et al., 1995). In the leaf record of the Jose Creek Member, the fossil record of Platanaceae is represented by *Platanus raynoldsii* (Upchurch and Mack, 1998) and forms similar to *Platanites marginatus*. Platanaceae were widely distributed in the Northern Hemisphere during the Cretaceous,

being known from leaves, woods, and reproductive structures.

Celastraceae are represented by *Baasia armendarisense* (Fig. 4A–C), which constitutes the first record of fossil wood of Celastraceae from North America (Estrada-Ruiz et al., 2012). Extant Celastraceae consist of 92 genera and 1350 species that are predominantly tropical in distribution, with some temperate representatives (Mabberley, 2008). Features diagnostic of Celastraceae include indistinct growth rings, bands of thick-walled fibers that alternate with regions of thin-walled fibers (Fig. 4A), predominantly solitary vessels with exclusively scalariform perforation plates (Fig. 4C, arrow), alternate to opposite intervessel pitting, vessel-ray parenchyma pitting similar to intervessel pitting (Fig. 4C), heterocellular rays (Figs. 4B, C) and some imperforate elements with bordered pits. The one known specimen of *B. armendarisense* represents an axis at least 14 cm in diameter and does not have the suite of anatomical features indicative of herb or vine habit. This suggests that the parent plant was a small tree or larger, depending on whether the specimen represents trunk wood or branch wood.

Myrtaceae are represented by *Fulleroxylon armendarisense* (Figs. 4D–F), which constitutes the first record of fossil wood of Myrtaceae in North America (Estrada-Ruiz et al., 2012). Extant Myrtaceae consist of 145 genera and 5500 species with wide distribution in tropical and warm-temperate regions of the world (Mabberley, 2008). Features diagnostic of Myrtaceae include diffuse porous wood with vessels that tend to be of two distinct diameters (Fig. 4D), exclusively simple perforation plates, vessel-ray parenchyma pits with reduced borders, vasicentric tracheids (tracheids that surround vessel elements) (Fig. 4E), diffuse axial parenchyma, and uniseriate to very rarely biseriate rays (Fig. 4F, arrows). Fossil woods of Myrtaceae have been reported from the latest Cretaceous to earliest Tertiary Deccan Intertrappan beds of India, and from the Early Tertiary of southern South America (Gregory et al., 2009). The one known specimen of *F. armendarisense* represents an axis 4.5 cm in diameter. In the absence of anatomical features indicative of a vine or herb, little can be said about growth habit.

Ericales are an order that makes up nearly 6% of extant eudicot diversity (Magallón-Puebla et al., 1999) and are a common element in Late Cretaceous wood floras from southern Western Interior (Wheeler and Lehman, 2009; Estrada-Ruiz et al., 2010). Two types of Ericales are present in the Jose Creek Member (Fig. 5A–D). Both are characterized by indistinct growth rings, over 90% solitary vessels, scalariform perforation plates, fewer than 50 bars per perforation plate, opposite to scalariform intervessel pitting, fiber-tracheids (cells intermediate between true tracheids and true fibers), and vasicentric tracheids (tracheids that surround the vessel elements). The two types differ in vessel density (14 vs. 36 vessels per mm<sup>2</sup>), whether or not some of the vessel-ray pits have reduced borders, and whether or not true fibers are present. One type (Figs. 5A–B) resembles DB.D1 Xylotype 2 from the Paleocene of the Denver Basin (Wheeler and Michalski, 2003). The other (Figs. 5C–D) conforms to Group IIIB from the Panoche Formation (Page, 1979).

Malpighiales are an order of tropical flowering plants that is structurally heterogeneous but forms a monophyletic group based

on molecular systematics. Extant Malpighiales consist of approximately 16,000 species and are an important component of the diversity of the understory in tropical rainforests (Davis et al., 2005). One wood type has a suite of features found in members of Euphorbiaceae (spurge family) and Chrysobalanaceae. This suite of features includes indistinct growth rings, diffuse porous wood, vessels that are solitary and in radial multiples (Fig. 5E), exclusively simple perforation plates (Fig. 5F, arrows), alternate and opposite to scalariform intervessel pits, vessel-ray parenchyma pits with reduced borders, diffuse axial parenchyma, and uniseriate to very rarely biseriate rays (InsideWood, 2004-onwards).

Magnoliids are a lineage of equal rank to eudicots and monocots. Extant magnoliids consist of the orders Magnoliales, Laurales, Canellales, and Piperales (APG, 2009; Stevens, 2001-onwards). *Pygmaeoxydon paucipora* (Estrada-Ruiz et al., 2012) is a magnoliid with small vessels that are solitary and in radial multiples (Fig. 5G), simple perforation plates, alternate intervessel pits, vessel-ray parenchyma pits with reduced borders, horizontally elongate parenchyma pits, rays up to 10 seriate, and enlarged cells in the rays with dark contents that probably represent oil cells (Fig. 5H, arrows). The combination of simple perforation plates and oil cells in the rays occurs only in Annonaceae (Magnoliales) and Lauraceae (Laurales). Rays in Lauraceae are generally no wider than 4 seriate, while rays in Annonaceae (custard apple family) are often very wide, with oil cells in the interior of the ray (InsideWood 2004-onwards; Estrada-Ruiz et al., 2012). The one known specimen of *P. paucipora* constitutes an axis approximately 2.5 cm in diameter. The high volume of parenchyma indicates that it may represent root wood.

### Angiosperms, Monocotyledons

A number of large monocot axes occur in the Jose Creek Member of the McRae Formation. Large monocot stems can be distinguished from “dicot” and conifer wood by their vascular and support tissues, which are organized into fibrovascular bundles that are scattered throughout the stem. Monocot roots can be recognized on the basis of a pith (a region of non-vascular tissue in the center), which is absent from “dicot” and conifer roots. Of the four monocot axes that have been sectioned, three have features characteristic of palms (family Arecaceae), and a fourth has a suite of features not yet found in any extant monocot.

Sectioned axes of Arecaceae (palms) consist of two stems, which we place in the genus *Palmoxylon*, and one stem fragment with attached roots, which we place in the genus *Rhizopal-moxylon*. *Palmoxylon* from McRae Formation is characterized by fibrovascular bundles randomly scattered in cross section (Fig. 6A). Each fibrovascular bundle has 1–12 protoxylem tracheary elements and 2 (very rarely 3) large metaxylem vessel elements. The metaxylem vessel elements have scalariform perforation plates and scalariform intervessel pitting (Fig. 6B, arrows). The ground tissue (i.e., the tissue surrounding the fibrovascular bundles) consists of two distinct cell types. The first surrounds the fibrovascular bundles and consists of compact cells, while the second forms the bulk of the ground tissue and consists of cells that are elongate to amoeboid in cross section and surround

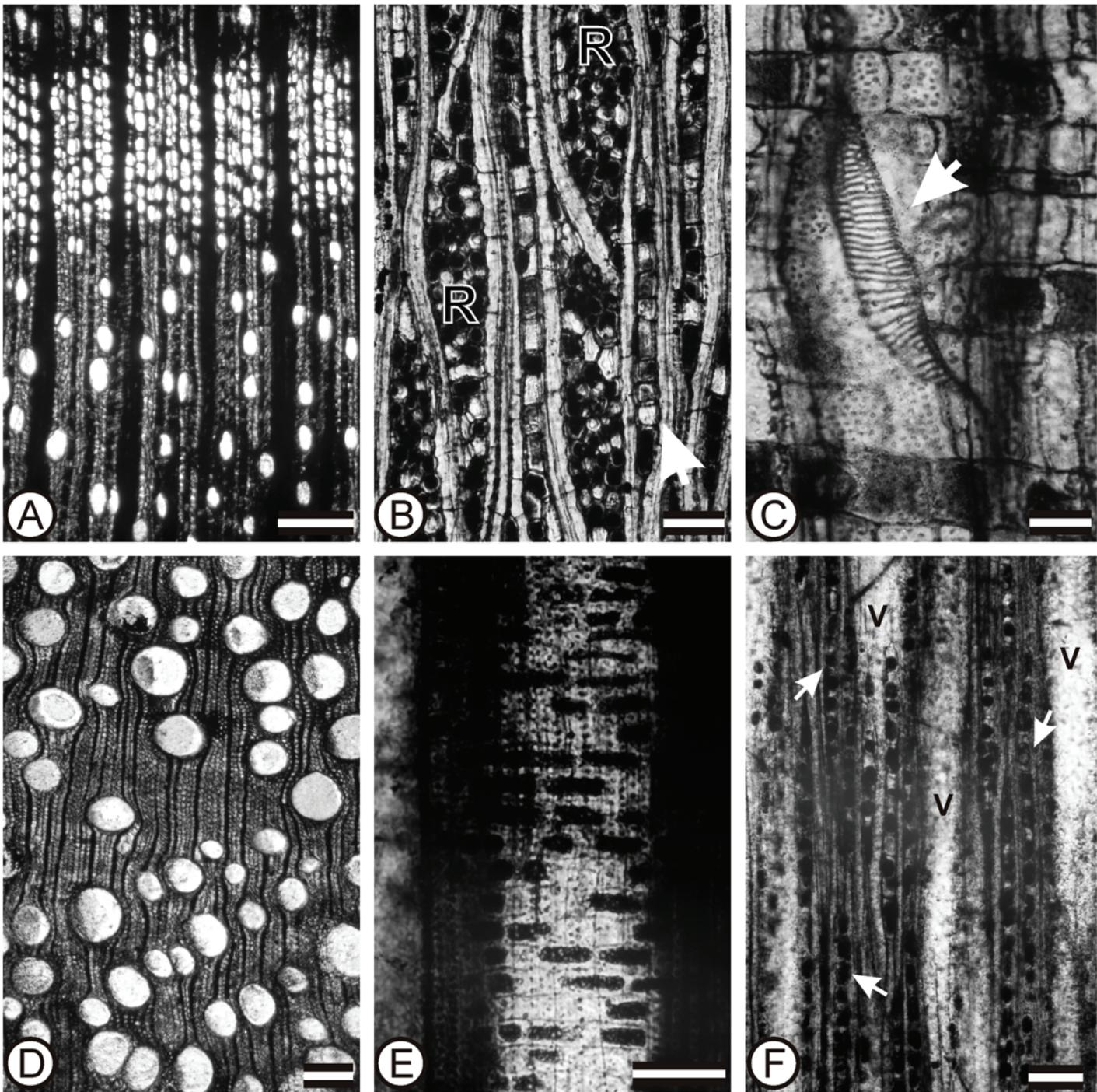


FIGURE 4. Celastraceae and Myrtaceae. **A–C**, Celastraceae. **A**, (TS) Wood showing alternating zones of thin-walled and thick-walled fibers, vessels predominantly solitary. TXSTATE 1200–S1. Scale = 264  $\mu\text{m}$ . **B**, (TLS) Uniseriate (arrow) and multiseriate rays (R) and imperforate tracheary elements with bordered pits. TXSTATE 1200–S4. Scale = 72  $\mu\text{m}$ . **C**, Scalariform perforation plate (arrow) and heterocellular ray. TXSTATE 1200–S9. Scale = 91  $\mu\text{m}$ . **D–F**, Myrtaceae. **D**, (TS) Vessels with tendency to be in two distinct diameter classes. TXSTATE 1201–S1. Scale = 176  $\mu\text{m}$ . **E**, (RLS) Vascentric tracheids. TXSTATE 1201–S6. Scale = 60  $\mu\text{m}$ . **F**, (TLS) Vessels (V) and uniseriate rays (arrows). TXSTATE 1201–S3. Scale = 60  $\mu\text{m}$ .

numerous small lacunae (air spaces). The oldest North American record of *Palmoxylon* comes from Coniacian–Santonian Magothy Formation of New Jersey (Berry, 1916), as does the oldest North American record of palm leaves. In Western North America and Mexico, *Palmoxylon* has been described from Paleogene Green River Formation of Utah (Tidwell et al., 1972), the Maastrichtian

Fox Hills Formation of Wyoming (Delevoryas, 1964), the Campanian Aguja Formation of Texas (Manchester et al., 2010) and the upper Campanian-lower Maastrichtian Olmos Formation of northern Mexico (Estrada-Ruiz and Cevallos-Ferriz, 2009).

The McRae *Rhizopalmoxylon* consists of numerous roots that originate from a stem (Fig. 6F). Each root has three well defined

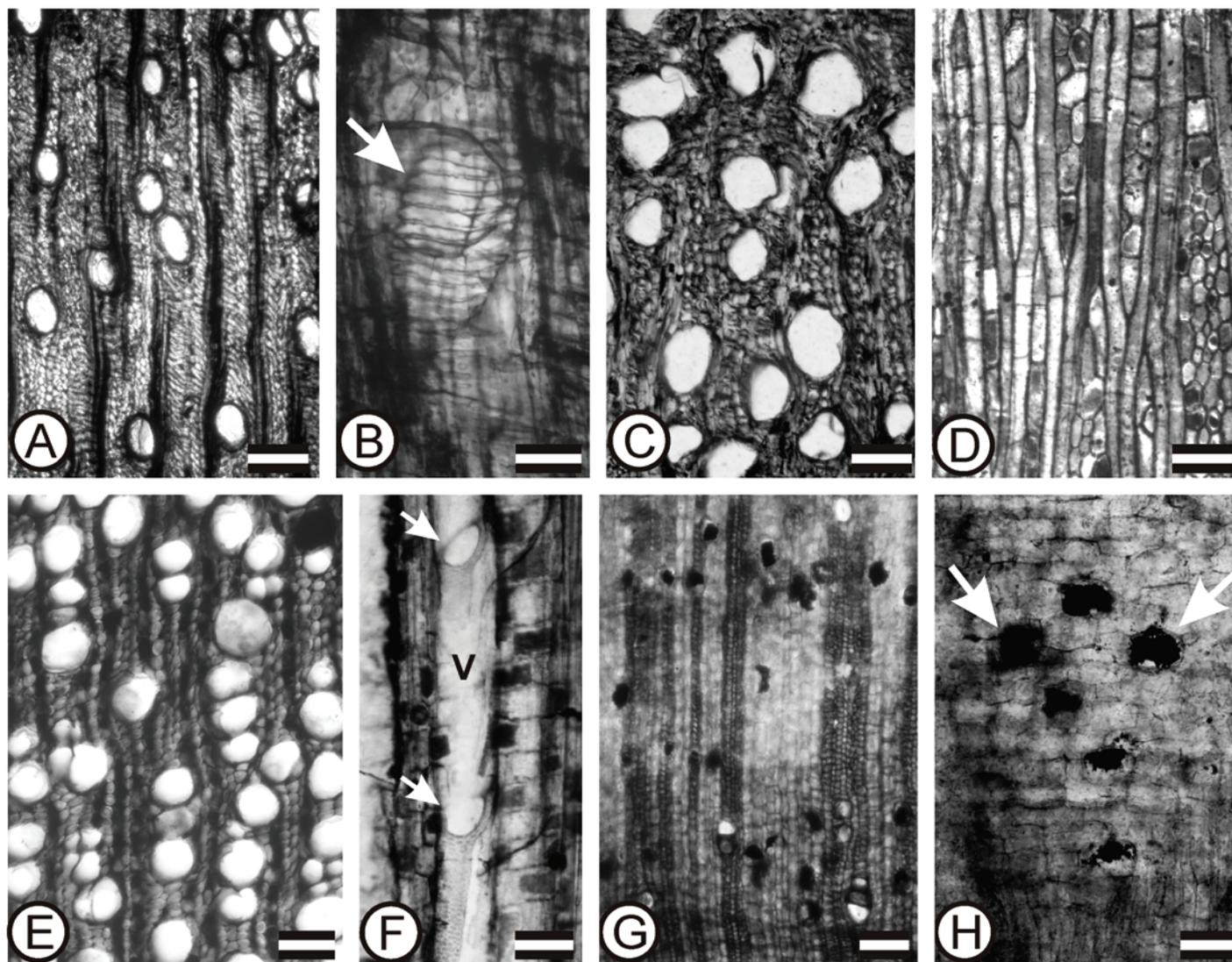


FIGURE 5. Ericales, Malpighiales, and Magnoliids. **A–B**, Ericales, Type I. **A**, (TS) Growth rings absent, solitary vessels. TXSTATE 1213–S1. Scale = 200  $\mu\text{m}$ . **B**, (RLS) Scalariform perforation plate (arrow). TXSTATE 1213–S8. Scale = 50  $\mu\text{m}$ . **C–D**, Ericales, Type II. **C**, (TS) Growth rings absent, solitary vessels. TXSTATE 1214–S1. Scale = 80  $\mu\text{m}$ . **D**, (TLS) Uniseriate and multiseriate rays. TXSTATE 1214–S5. Scale = 73  $\mu\text{m}$ . **E**, (TS) Solitary vessels and in multiples radial, without growth ring. TXSTATE 1202–S1. Scale = 96  $\mu\text{m}$ . **F**, (RLS) Vessel element (V) with simple perforation plate (arrows). TXSTATE 1202–S8. Scale = 45  $\mu\text{m}$ . **G**, Growth rings absent, vessels solitary and in radial multiples, wide rays. TXSTATE 1204–S3. Scale = 192  $\mu\text{m}$ . **H**, (RLS) Some ray cells slightly enlarged and with dark contents (arrows). TXSTATE 1204–S10. Scale = 192  $\mu\text{m}$ .

areas: epidermis, cortex and vascular cylinder (Fig. 6F). The cortex is divided into two distinct zones of cells, and the vascular cylinder has a distinct endodermis, a ring of primary xylem with vessel elements, and pith. The number of vessel elements is greater in large-diameter roots than in small-diameter roots. *Rhizophalmoxylon* has fewer reported occurrences than *Palmoxylon*, being reported in Western US North America from the Tertiary (Eocene) Dipping Vat Formation of central Utah, USA (Tidwell et al., 1972).

A third type of axis represents a monocot stem with compound fibrovascular bundles (Fig. 6C, arrows) and simple (Fig. 6E) and scalariform perforation plates (Fig. 6D). Compound fibrovascular bundles consist of two or more fibrovascular bundles that are

fused together to form a larger structure. Most monocots, including all palms, have simple fibrovascular bundles (Fig. 6A). Within extant monocots, compound fibrovascular bundles occur in the order Pandanales (Tomlinson and Wilder, 1984), in the families Pandanaceae (screw pine family) and Cyclanthaceae (panama hat family). The Jose Creek fossil is not a close match for either of these families because its compound vascular bundles consist of individual fibrovascular bundles that are fused together in a side-by-side pattern. Extant Pandanaceae and Cyclanthaceae have the individual fibrovascular bundles fused to form a small ring, with the xylem to the inside and the phloem and fibers to the outside (Tomlinson and Wilder, 1984; Tomlinson, written communication, 2010).

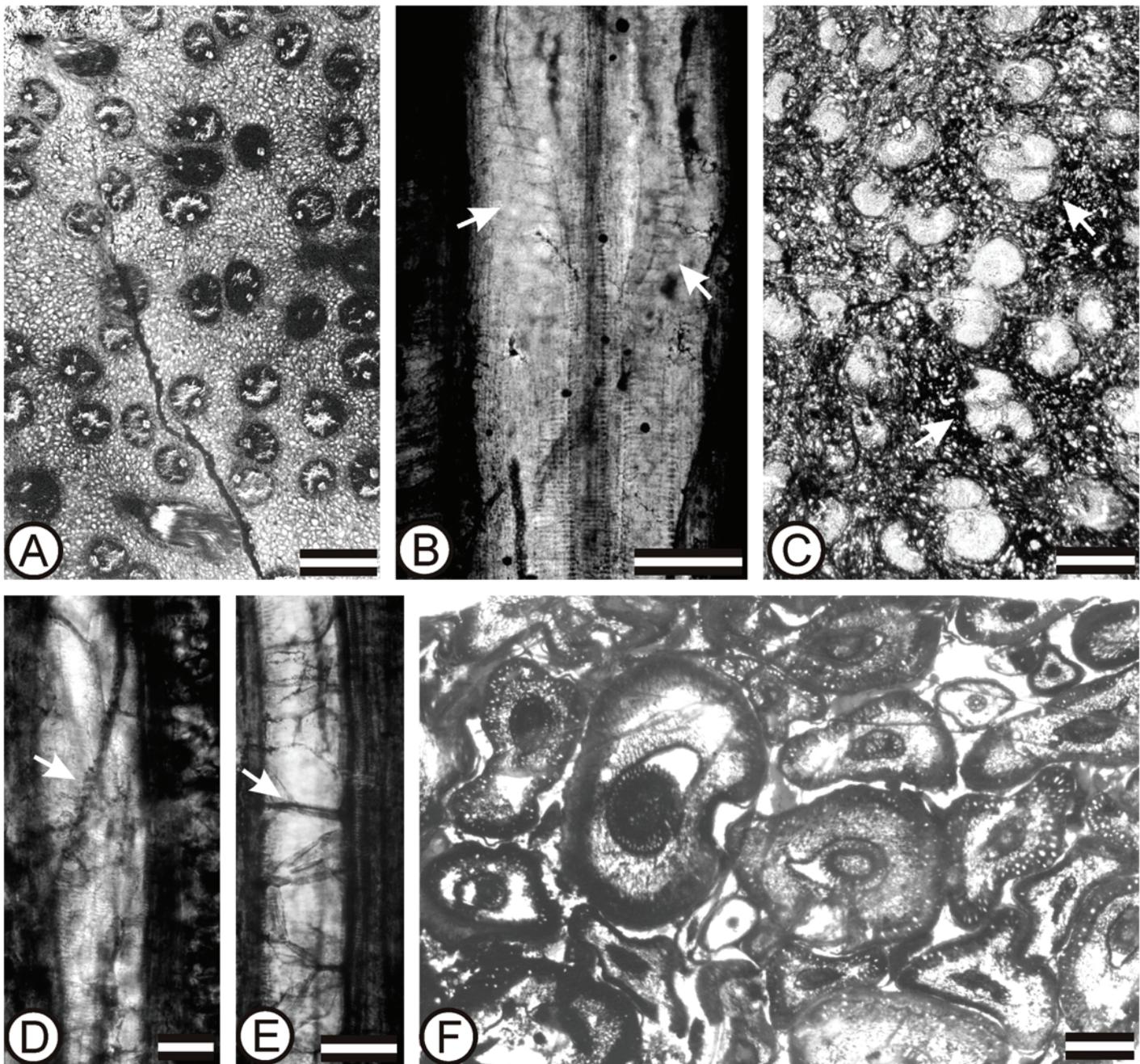


FIGURE 6. Monocots. **A**, *Palmoxylon* sp. (TS) General view showing scattered distribution of the fibrovascular bundles. TXSTATE 1215-S1. Scale bar = 2200  $\mu$ m. **B**, (TLS) Scalariform perforation plate (arrows) and intervessel pits. TXSTATE 1215-S5. Scale bar = 150  $\mu$ m. **C-E**, Unknown monocot. **C**, (TS) General view showing scattered distribution of the simple and compound vascular bundles (arrows). TXSTATE 1216-S1. Scale bar = 1360  $\mu$ m. **D**, (TLS) Scalariform perforation plate (arrow). TXSTATE 1216-S12. Scale bar = 68  $\mu$ m. **E**, (TLS) Simple perforation plate (arrow). TXSTATE 1216-S12. Scale bar = 110  $\mu$ m. **F**, *Rhizopalmoxylon* (TS) General view showing the roots. TXSTATE 1217-S1. Scale bar = 2400  $\mu$ m.

### Conifers, Jose Creek Member, McRae Formation

#### Jose Creek Member, McRae Formation

Conifer woods are common in the Jose Creek Member of the McRae Formation. Assigning valid taxonomic names to these and other Cretaceous conifer woods is problematic. Conifer

woods are simpler in their anatomy than angiosperm woods, so the number of characters for conifer wood identification is limited, and a single species or even single individual can show significant anatomical variation (for example, wood in *Sequoia*, the coast Redwood; Bailey and Faull, 1934). The names used for fossil conifer woods are problematic due to misidentifications and the introduction of synonyms over the years, when woods

were named without careful comparison to or knowledge of previously named taxa. Efforts are underway to solve the nomenclatural problems for fossil conifer wood, but the most recent work has not yet been published (e.g., M. Philippe, written communication, 2011). For these reasons we assign the conifer woods to general morphotypes and provide photographs to document diversity.

### Araucarioid conifers

The araucarioid group of fossil conifer woods is characterized by a pattern of tracheid pitting found in extant Araucariaceae (Wheeler and Lehman, 2005) (Figs. 7D, 7G). In this pattern the pits are confluent with each other and flattened along their zone of contact. When two or more rows of pits are present in a tracheid, the pits alternate with each other along the length of the tracheid rather than being opposite as in other conifers (Figs. 7D, 7G). Among Cretaceous conifers, this pattern of pitting is found in the families Araucariaceae and Cheirolepidiaceae, the latter now extinct.

Two types of McRae woods have the araucarioid pattern of tracheid pitting. Araucarioid Type I is characterized by the absence of growth rings (Fig. 7A). Tracheid pits are crowded, uniseriate or alternately arranged. Biseriate and triseriate pitting are most common, but up to five rows of pits have been observed (Fig. 7D). When uniseriate, pits are xenoxylean (i.e., contiguous, flattened, up to twice as wide as tall) (Phillipe and Bamford, 2008). The cross-field pits are araucarioid, arranged as 1–4 opposite pits in a single row or 3–9+ alternate pits crowded in multiple rows (Fig. 7C, arrows). The rays are uniseriate, averaging 6 cells tall, with the tallest rays under 20 cells in height (Fig. 7B). One cavity has been observed in cross section (Fig. 7A). Although tempting to interpret it as a resin duct, this cavity may represent an area where the wood was penetrated by some biological agent.

Araucarioid Type II is also characterized by the absence of growth rings (Fig. 7E). This type has predominately uniseriate, xenoxylean tracheid pitting, but biseriate alternate pitting is common (Fig. 7G), and triseriate alternate pitting is also present. The one to four pits per cross-field are either alternate or opposite in arrangement, in one or two rows. Compared to Araucarioid Type I, the cross-field pits are generally larger, rounded, and less crowded. Axial parenchyma cells are present (Fig. 7E, isolated dark cells). The rays are uniseriate, average five cells tall, and are rarely more than 10 cells tall (Fig. 7F). Resin canals are absent. These characters are consistent with *Agathoxylon* (Bamford and Philippe, 2001).

### Taxodioid conifers

Taxodioid conifers share a combination of traits that occur in modern conifers that were once placed within the family Taxodiaceae (bald cypress family). This group is now recognized as the primitive evolutionary grade in the family Cupressaceae and includes the Coast Redwood (*Sequoia*), Giant Sequoia (*Sequoiadendron*), and Dawn Redwood (*Metasequoia*).

The largest *in situ* stump found in the Jose Creek Member is a taxodioid conifer (Fig. 8A-c). The stump measures 1.5 m in

diameter at the top of the buttress roots. It is rooted in a paleosol that is overlain by a recrystallized volcanic ash. The ash contains diverse leaf remains, including those of a taxodioid conifer. Growth rings are generally absent in this wood (Fig. 8A). However, a single isolated ring was observed near the periphery of the trunk, perhaps produced by the tree as a response to being inundated with volcanic ash. Tracheid pitting is predominantly uniseriate, with crassulae (transverse wall thickenings between pits) sometimes present (Fig. 8C). Occasionally zones of biseriate opposite pitting are present. The rays show wide variation in size. Less than half the rays are uniseriate as is typical for most conifers, whereas more than half the rays are either biseriate or triseriate (as is often seen in taxodioid conifers, especially in their roots) (Fig. 8B). The rays average 12 cells tall and can be up to 40 cells tall (Fig. 8B). Axial parenchyma is rare to absent, but septate tracheids are abundant (Fig. 8B, arrow). Cross-field pitting usually consists of 1–2 (rarely 3) oppositely arranged pits (Fig. 8C, arrows).

### Cupressoid/podocarpoid conifers

The cupressoid/podocarpoid group is a collection of taxa that share a combination of traits unique to extant Cupressaceae and Podocarpaceae (Phillips, 1948). These traits include uniseriate tracheid pitting that is opposite when multiseriate, 1–2 cupressoid to taxodioid pits per cross-field, predominantly uniseriate rays, and parenchyma with smooth walls.

Four of the McRae conifer wood types fit within the cupressoid/podocarpoid category as outlined by Wheeler and Lehman (2005). They exhibit uniseriate or opposite tracheid pitting, cupressoid to taxodioid cross-field pitting, and lack resin canals. They differ in the presence or absence of growth rings, cross-field pit type and arrangement, ray height, and the presence or absence of axial parenchyma. The number of species is unclear. More sectioned specimens are needed to determine whether the anatomical variation between specimens is continuous or discontinuous.

Cupressoid/Podocarpoid Type I is characterized by the absence of growth rings (Fig. 8D). Rays are uniseriate, average five cells tall, and are mostly 1–10 cells tall (Fig. 8E). Tracheid pitting is generally uniseriate and predominantly abietinean (that is, rounded, separated by crassulae or widely spaced, with fewer than 10% contiguous—Phillipe and Bamford, 2008). Occasional areas of biseriate pitting are present, with oppositely arranged pits. Cross-field pits (Fig. 8F, arrows) are predominantly taxodioid, but cupressoid type pits are also common. Abundant axial parenchyma is visible in cross-section (Fig. 8D, dark cells). This wood has features consistent with the “cupressoid/podocarpoid, short ray, growth rings not observed” category of the Javelina Formation as described by Wheeler and Lehman (2005).

## DISCUSSION

The wood floras of the Ash Canyon Member of the Crevasse Canyon and the Jose Creek Member of the McRae Formation expand the number of taxa and occurrences of Late Cretaceous angiosperm and conifer wood. Perhaps most significant are the

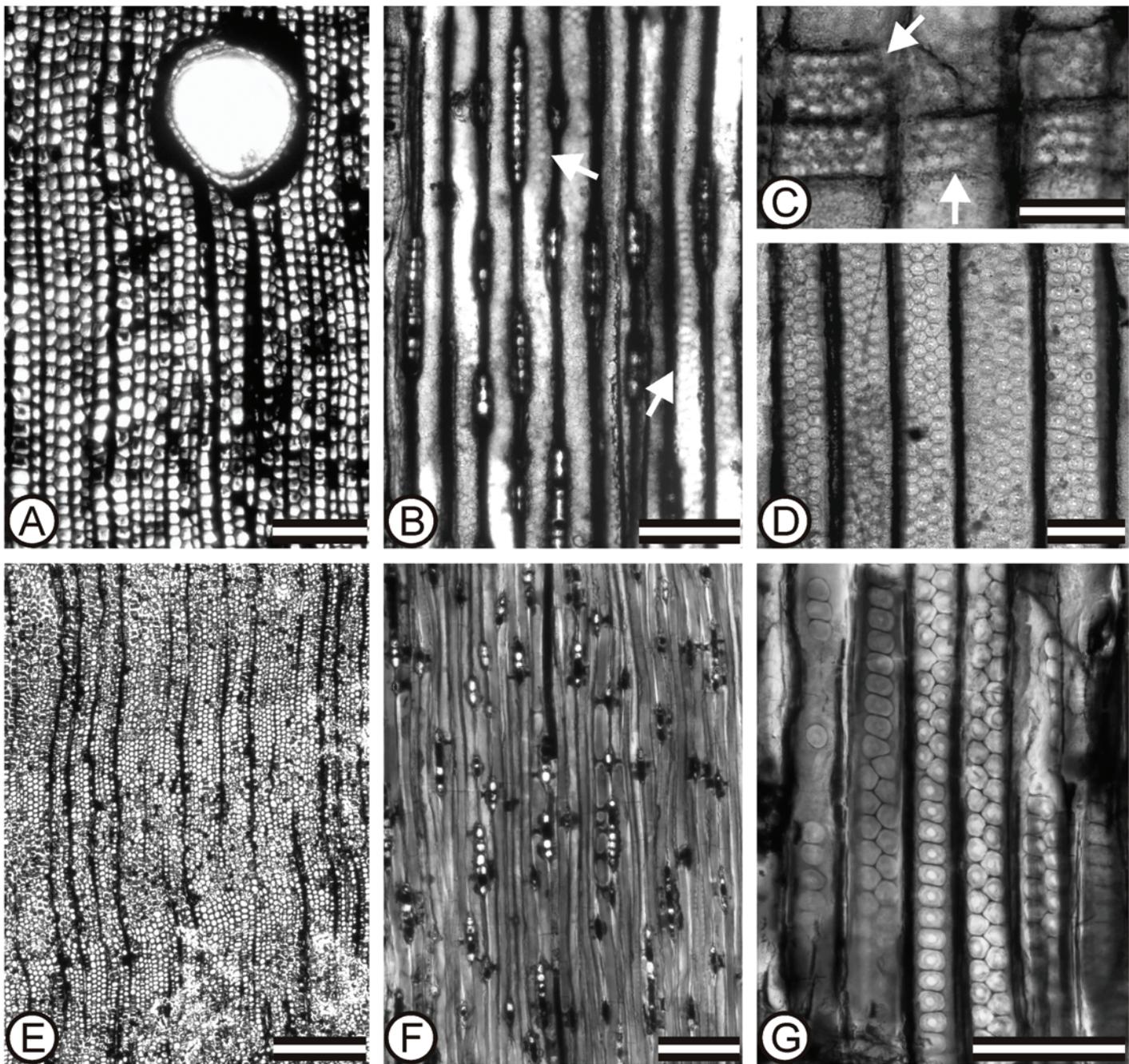


FIGURE 7. Araucarioid Type Conifers. A–D, Araucarioid Type I, A, (TS) Growth rings absent. TXSTATE 1218–S1. Scale bar = 500  $\mu\text{m}$ . B, (TLS) Uniseriate rays averaging 5 cells tall (arrows). TXSTATE 1218–S5. Scale bar = 200  $\mu\text{m}$ . C, (RLS) Araucarioid cross-field pitting (arrows). TXSTATE 1223–S1. Scale bar = 50  $\mu\text{m}$ . D, Araucarioid tracheid pitting, up to 5 rows of alternate pits. TXSTATE 1218–S10. Scale bar = 90  $\mu\text{m}$ . E–G, Araucarioid Type II. E, (TS) General view showing absence of growth rings. TXSTATE 1219–S1. Scale bar = 500  $\mu\text{m}$ . F, (TLS) Uniseriate rays averaging 6 cells tall. TXSTATE 1219–S2. Scale bar = 200  $\mu\text{m}$ . G, (RLS) Tracheid pitting, combination of uniseriate and xenoxylean or alternate. TXSTATE 1219–S6. Scale bar = 90  $\mu\text{m}$ .

occurrences of Celastraceae (*Baasia*) and Myrtaceae (*Fulleroxylon*) in the Jose Creek Member. These constitute the first occurrences of Celastraceae and Myrtaceae in the fossil wood record of North America (Estrada-Ruiz et al., 2012). Our studies also indicate the importance of certain taxa in Late Cretaceous vegetation. A prime example is the eudicot *Metacalfeoxylon*, which was an

important component of forests from the Campanian–Maastrichtian of the southern Western Interior, including Big Bend, Texas, the Four Corners region, New Mexico, and Coahuila, Mexico (Wheeler and Lehman, 2000; Estrada-Ruiz et al., 2010, 2012).

Comparison of the wood record with the leaf macrofossil record of the Jose Creek Member indicates congruence between

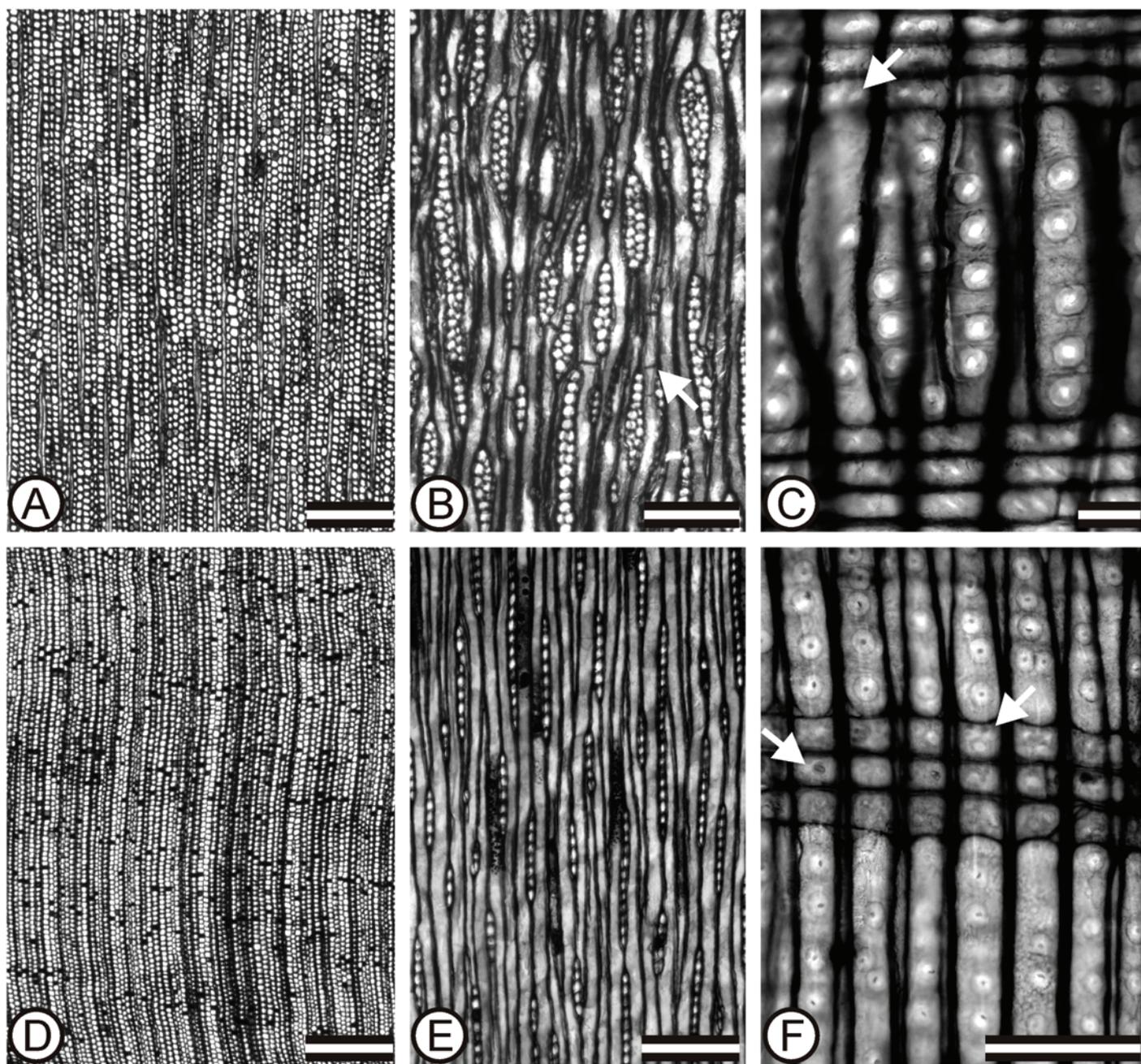


FIGURE 8. Taxodioid and Cupressoid/Podocarpoid Type Conifers. **A–C**, Taxodioid conifer. **A**, (TS) General view showing the absence of growth rings. TXSTATE 1220–S5. Scale bar = 500  $\mu\text{m}$ . **B**, (TLS) Septate tracheids (arrow) and biseriate to triseriate rays. TXSTATE 1220–S12. Scale bar = 200  $\mu\text{m}$ . **C**, (RLS) Uniseriate tracheid pitting and cross-field pitting with 1–2 (up to 4) pits per cross-field (arrow). TXSTATE 1220–S21. Scale bar = 90  $\mu\text{m}$ . **D–F**, Cupressoid/Podocarpoid Type II. **D**, (TS) General view showing growth rings absent; parenchyma abundant. TXSTATE 1221–S3. Scale bar = 500  $\mu\text{m}$ . **E**, (TLS) Uniseriate rays. TXSTATE 1221–S4. Scale bar = 200  $\mu\text{m}$ . **F**, (RLS) Abietinean tracheid pitting and cross-field pitting with 1–3 taxodioid pits per cross-field (arrows). TXSTATE 1221–S9. Scale bar = 90  $\mu\text{m}$ .

taxonomic affinities provided by woods and leaves. For angiosperms, both woods and leaves indicate the presence, in the Cutter Sag/Love Ranch Basin, of the extant families Platanaceae, Lauraceae, and Arecaceae during the Campanian–Maastrichtian (cf. Upchurch and Mack, 1998). Araucarioid woods correspond to the presence, in the leaf record, of Araucariaceae (*Brachyphyl-*

*lum macrocarpum*, *Araucarites*-type shoots, and a recently discovered araucarian cone scale) and probable Cheirolepidiaceae (aff. *Androvettia*) (cf. Upchurch and Mack, 1998; unpublished data). Taxodioid wood is congruent with the occurrence of a fossil redwood showing similarities to the species *Metasequoia cuneata* (reported as “*Sequoia*” *obovata* by Upchurch and Mack,

1998). Patterns of co-occurrence also reinforce these affinities. Araucarioid Type I occurs in a bed of volcanic ash that yields abundant shoots and a cone scale of Araucariaceae. The large taxodioid stump is rooted in a paleosol immediately beneath a volcanic ash that preserves a number of taxa, including shoots showing similarities to *Metasequoia cuneata*.

In some cases there is no direct correspondence between the woods and leaves of our study area. However, leaf macrofossil records from more northern regions of the Western Interior indicate the presence of the same taxonomic groups. These include Celastraceae and Euphorbiaceae, which are reported from Cretaceous-Tertiary boundary sections in the Raton Basin of New Mexico and Colorado (Wolfe and Upchurch, 1987a). In other cases lack of correspondence between the wood and leaf record might reflect poor preservation or be another example of differences between families in which organs are most likely to be preserved. Myrtaceae are one example, because leaves assigned to *Myrtophyllum* usually have insufficient preservation to determine their real taxonomic affinities (Upchurch and Dilcher, 1990). This is reinforced by the fact that flowers of Myrtaceae are known from the Turonian of the Atlantic Coastal Plain (Crepet, 2008), and leaves of Myrtaceae with attached reproductive structures are known from the Eocene of Western North America (Manchester et al., 1998). Myrtaceae are well represented in the Cenozoic floras of the Southern Hemisphere (Friis et al., 2011).

The fossil wood record of the southern Western Interior shows a number of common elements during the Campanian–Maastrichtian. *Paraphyllanthoxylon* and *Metcalfeoxylon* from Crevasse Canyon Formation, and *Platanoxylon*, *Palmoxylon*, and diverse conifer wood types from McRae Formation, provide further evidence of elements shared with other localities from the Western Interior. For example, *Metcalfeoxylon* is known from the Kirtland Formation (Wheeler et al., 1995), Aguja Formation (Wheeler et al., 1995; Wheeler and Lehman, 2000) and Olmos Formation (Estrada-Ruiz et al., 2010). *Metcalfeoxylon* occurs as *in situ* stumps in the Crevasse Canyon and Aguja formations and may have represented tropical evergreen trees up to 40–50 m tall (Lehman and Wheeler, 2001; Upchurch et al., 2003). *Paraphyllanthoxylon anazasii* is known from the Kirtland and Aguja formations. *Platanoxylon* occurs in the Kirtland and Aguja formations and the Panoche Formation (Campanian–Maastrichtian) of California (Page, 1968; Wheeler et al., 1995). Of the occurrences of *Platanoxylon*, only *Platanoxylon* sp. 2 from McRae Formation is known *in situ* and comes from a stump that measures 40 cm diameter above the buttress roots, indicating that it probably represents a small tree. Large monocots also were an important element in the subtropical and tropical areas of the Western Interior. *Palmoxylon* has been collected from the McRae, Aguja and Olmos formations. This supports the concept of a common flora in the southern Western Interior during the Campanian–Maastrichtian that existed under warm subtropical to paratropical temperatures and moisture conditions ranging from semi-arid to rainforest (e.g., Upchurch et al., 1999; Estrada-Ruiz et al., 2008).

The absence of well-defined growth rings in all angiosperm wood types, and the absence of growth rings in half the conifer wood types, reinforce evidence from leaf macrofossils for

the presence of warm subtropical to paratropical climates in the Cutter Sag/Love Ranch Basin and the southern Western Interior during the Campanian–Maastrichtian (Wolfe and Upchurch, 1987b; Upchurch and Wolfe, 1993; Upchurch and Mack, 1998; Estrada-Ruiz et al., 2008). The presence of palms in the Jose Creek wood flora reinforces evidence from palm leaf macrofossils for a mean annual temperature greater than 13°C and a cold-month mean temperature greater than 5°C, based on the temperature tolerances of living palms (Markwick, 2007). The presence of palm wood also reinforces evidence from paleosols for year-round precipitation during the deposition of the Jose Creek Member (Buck and Mack, 1995), based on the need for living palms to have a readily available source of water (Francko, 2003).

The pattern of conifer wood co-occurrence in the Jose Creek Member is of particular interest in light of conifer wood distribution in other areas. In Big Bend, Texas, cupressoid/podocarpoid and taxodioid woods show a different pattern of geographic distribution from araucarioid woods. Cupressoid/podocarpoid and taxodioid woods are abundant near the coast and absent from more interior regions, while araucarioid woods are absent from the coast and occur abundantly in the interior (Wheeler and Lehman, 2005). A similar pattern is present in the Kirtland Formation of the Four Corners region, New Mexico, where a coastal *in situ* fossil forest is dominated by large trunks of *Cupressinoxylon* (Davies-Vollum et al., 2011). For Big Bend, this pattern of ecological segregation has been attributed to climatic and edaphic differences between coastal and interior environments, in particular the presence of wetter climates and waterlogged soils in coastal environments, and drier climates and well-drained soils in interior environments (Wheeler and Lehman, 2005). The conifer wood flora of the Jose Creek Member has both coastal and interior groups occurring together in the same restricted area, rather than separated by more than one hundred kilometers as in Big Bend. This may be due to the co-occurrence of environmental factors in south-central New Mexico that were spatially segregated in Big Bend, Texas. We propose that, in the Jose Creek Member, the critical mix of environmental factors was the presence of a humid to wet climate combined with an abundance of well-drained soils (Buck and Mack, 1995).

#### ACKNOWLEDGMENTS

We thank owner Ted Turner and manager Tom Wadell for allowing us access to the Armendaris Ranch to sample the McRae Formation. We thank Dr. H. Nishida (Chuo University, Tokyo, Japan) for bibliographic information. We thank the Department of Geography, Texas State University, for providing us with access to their thin section laboratory. Collection and early analysis of the fossil woods was supported by National Science Foundation Grant BSR-9024820 to G.R. Upchurch, and an American Chemical Society Petroleum-Research Fund Grant to G.H. Mack. This study is based on the Postdoctoral Project of EER (*Estancias Posdoctorales y Sabáticas al Extranjero para la Consolidación de Grupos de Investigación*) from CONACyT (137526 and 155404), Mexico, at the Department of Biology, Texas State University, San Marcos, Texas, USA. The analyses of monocot

and conifer woods constitute class projects by Mindy Murray, Joan Parrott, and Dori Thompson for the Fall 2010 offering of Biology 7308, History of Vegetation and Climate, at Texas State University, San Marcos.

## REFERENCES

- APG III [Angiosperm Phylogeny Group III], 2009, An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III: Botanical Journal of the Linnean Society, v. 161, p. 105–121.
- Ash, S. R. and Tidwell, W. D., 1976, Upper Cretaceous and Paleocene floras of the Raton Basin, Colorado and New Mexico: New Mexico Geological Society, Guidebook 27th Fall Field Conference, p. 197–203.
- Bailey, I. W. and Faull, A. E., 1934, The cambium and its derivative tissues, IX. Structural variation in the redwood, *Sequoia sempervirens*, and its significance in the identification of fossil woods: Journal of the Arnold Arboretum, v. 15, p. 99–106.
- Bamford, M. and Philippe, M., 2001, Gondwanan Jurassic-Early Cretaceous homoxylous woods: a nomenclatural revision of the genera with taxonomical notes: Review of Palaeobotany and Palynology, v. 113, p. 287–297.
- Berry, E. W., 1916, A petrified palm from the Cretaceous of New Jersey: American Journal of Science, v. 41, p. 193–197.
- Bogner, J., Johnson, K. R. and Kvaček, Z., Upchurch, G. R. Jr., 2007, New fossil leaves of Araceae from the Late Cretaceous and Paleogene of western North America: Zitteliana, v. A47, p. 133–147.
- Buck, B. J. and Mack, G. H., 1995, Latest Cretaceous (Maastrichtian) aridity indicated by paleosols in the McRae Formation, south-central New Mexico: Cretaceous Research, v. 16, p. 559–572.
- Cahoon, E. J., 1972, *Paraphyllanthoxylon alabamense*—a new species of fossil dicotyledonous wood: American Journal of Botany, v. 59, p. 5–11.
- Crepet, W. L., 2008, The fossil record of angiosperms: Requiem or renaissance: Annals of the Missouri Botanical Garden, v. 95, p. 3–33.
- Davies-Vollum, K. S., Boucher, L. S., Hudson, P. and Proskurowski, A. Y., 2011, A late Cretaceous coniferous woodland from the San Juan Basin, New Mexico: Palaios, v. 26, p. 89–98.
- Davis C. C., Webb C. O., Wurdack K. J., Jaramillo C. A. and Donoghue M. J., 2005, Explosive radiation of Malpighiales supports a mid-Cretaceous origin of tropical rain forests: American Naturalist, v. 165, p. E36–E65.
- Delevoryas, T., 1964, Two petrified angiosperms from the Upper Cretaceous of South Dakota: Journal of Paleontology, v. 38, p. 584–586.
- Détienne, P. and Jacquet, P., 1983, Atlas d'identification des bois de l'Amazonie et des régions voisines. Centre Technique Forestier Tropical, Nogent-sur-Marne, France, 640 p.
- Estrada-Ruiz, E. and Cevallos-Ferriz, S. R. S., 2009, *Palmoxylenochii* sp. nov. de la Formación Olmos (Campaniano superior-Maastrichtiano inferior), Coahuila, México: Ameghiniana, v. 46, p. 577–585.
- Estrada-Ruiz, E., Martínez-Cabrera, H. I. and Cevallos-Ferriz, S. R. S., 2007, Fossil woods from the late Campanian-early Maastrichtian Olmos Formation, Coahuila, Mexico: Review of Palaeobotany and Palynology, v. 145, p. 123–133.
- Estrada-Ruiz, E., Martínez-Cabrera, H. I. and Cevallos-Ferriz, S. R. S., 2010, Fossil woods from the Olmos Formation (late Campanian-early Maastrichtian), Coahuila, Mexico: American Journal of Botany, v. 97, p. 1179–1194.
- Estrada-Ruiz, E., Upchurch, G. R., Jr. and Cevallos-Ferriz, S. R. S., 2008, Flora and climate of the Olmos Formation (upper Campanian-lower Maastrichtian), Coahuila, Mexico: A preliminary report: Gulf Coast Association of Geological Societies Transactions, v. 58, p. 273–283.
- Estrada-Ruiz, E., Upchurch, G. R., Jr., Wolfe, J. A. and Cevallos-Ferriz, S. R. S., 2011, Comparative morphology of fossil and extant leaves of Nelumbonaceae, including a new genus from the Late Cretaceous of Western North America: Systematic Botany, v. 32, p. 337–351.
- Estrada-Ruiz, E., Upchurch, G. R. Jr, Wheeler, E. A. and Mack, G., 2012, Late Cretaceous angiosperm woods from the Crevasse Canyon and McRae formations, south-central New Mexico, USA: part 1: International Journal of Plant Sciences, v.173, p.412–428.
- Evert, R. F., 2006, Esau's plant anatomy, meristems, cells, and tissues of the plant body: their structure, function, and development. 3rd edn. New Jersey, John Wiley and Sons, Inc., 624 p.
- Francko, D.A., 2003, Palms won't grow here and other myths. Warm-climate plants for cooler areas. Portland, Oregon, Timber Press Inc., 267 p.
- Friis, E. M., Crane, P. R. and Pedersen, K. R., 2011, Early flowers and angiosperm evolution. Cambridge, Cambridge University Press, 596 p.
- Gillette, D. D., Wolberg, D. L. and Hunt, A. P., 1986, *Tyrannosaurus rex* from the McRae Formation (Lancian, Upper Cretaceous), Elephant Butte Reservoir, Sierra County, New Mexico. New Mexico Geological Society, Guidebook 37<sup>th</sup> Fall Field Conference, p. 235–238.
- Gregory, M., Poole, I. and Wheeler, E. A., 2009, Fossil dicot wood names, an annotated list with full bibliography: IAWA J., Supplement 6.
- Gryc, V., Vavřík, H. and Sakala, J., 2009, Cenomanian angiosperm wood from the Bohemian Cretaceous Basin, Czech Republic: IAWA Journal, v. 30, p. 319–329.
- Haas, H. and Rowe, N. P., 1999, Thin sections and wafering; in Jones T. P. and Rowe, N. P., eds., Fossil plants and spores: Modern techniques: Geological Society, London, UK, p. 76–81.
- Herendeen, P. S., 1991, Lauraceous wood from the mid-Cretaceous Potomac Group of eastern North America: *Paraphyllanthoxylon marylandense* sp. nov.: Review of Palaeobotany and Palynology, v. 69, p. 277–290.
- Hudson, P. J., 2006, Taxonomic and paleoclimatic significance of Late Cretaceous wood from the San Juan Basin, New Mexico [M.S. Thesis]: Omaha, The University of Nebraska, 82 p.
- IAWA Committee, 1989, List of microscopic features for hardwood identification. IAWA Bulletin, v. 10, p. 219–329.
- IAWA Committee, 2004, List of microscopic features for softwood identification. IAWA Bulletin v. 25, p. 1–70.
- Ilic, J., 1987, The CSIRO Family Key for Hardwood Identification. E.J. Brill, Leiden, Netherlands, 171 p.
- Ilic, J., 1991, CSIRO Atlas of Hardwoods. Springer-Verlag, Berlin, Germany, 525 p.
- InsideWood 2004-onwards Published on the Internet. <http://insidewood.lib.ncsu.edu/search>.
- Johnson, K. R., Reynolds, M. L., Werth, K. W. and Thomasson, J. R., 2003, Overview of the Late Cretaceous, early Paleocene, and early Eocene megaflores of the Denver Basin, Colorado; in Johnson, K. R., Reynolds, R. G. and Reynolds, M. L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin, Pt. II: Rocky Mountain Geology, v. 38, p. 101–120.
- Knowlton, F. H., 1917, Fossil floras of the Vermejo and Raton formations of Colorado and New Mexico: U. S. Geological Survey, Professional Paper 101, p. 223–450.
- Lehman, T. M. and Wheeler, E. A., 2001, Fossil dicotyledonous forest from the Upper Cretaceous of Big Bend National Park, Texas: Palaios, v. 16, p. 102–108.
- Lozinsky, R. P., Hunt, A. P., Wolberg, D. L. and Lucas, S. G., 1984, Late Cretaceous (Lancian) dinosaurs from the McRae Formation, Sierra County, New Mexico: New Mexico Geology, v. 6, p. 72–77.
- Lucas S.G., Mack, G. M. and Estep, J. W., 1998, The ceratopsian dinosaur *Torosaurus* from the Upper Cretaceous McRae Formation, Sierra County, New Mexico: New Mexico Geological Society, Guidebook 49<sup>th</sup> fall Field Conference, p. 223–227.
- Mabberley, D. J., 2008, Mabberley's plant-book. A portable dictionary of plants, their classification and uses. Third edition, Cambridge, Cambridge University Press.
- Magallón-Puebla, S., Crane, P. R. and Herendeen, P.S., 1999, Phylogenetic pattern, diversity and diversification of eudicots: Annals of the Missouri Botanical Garden, v. 86, p. 297–372.
- Manchester, S. R., Dilcher, D.L., and Wing, S.L., 1998, Attached leaves and fruits of myrtaceous affinity from the Middle Eocene of Colorado: Review of Palaeobotany and Palynology, v. 102, p. 153–163.
- Manchester, S. R., Lehman, T. M. and Wheeler, E. A., 2010, Fossil palms (Arecaceae, Coryphoideae) associated with juvenile herbivorous dinosaurs in the Upper Cretaceous Aguja Formation, Big Bend National Park, Texas: International Journal of Plant Sciences, v. 171, p. 679–689.
- Markwick, P. J., 2007, The palaeogeographic and palaeoclimatic significance of climate proxies for data-model comparisons; in Williams, M., Haywood, A., Gregory, F., and Schmidt, D., eds., Deep-time perspectives on climate

- change: marrying the signal from computer models and biological proxies: The Micropalaeontology Society, Special Publication 15, The Geological Society of London, London, p. 251–312.
- Meijer, J.J.F., 2000, Fossil woods from the Late Cretaceous Aachen Formation: Review of Palaeobotany and Palynology, v. 112, p. 297–336.
- Metcalfe, C. R. and Chalk, L., 1950, Anatomy of dicotyledons, vols. 1 and 2. Clarendon Press, Oxford, UK, 1500 p.
- Molenaar, C. M., 1983, Major depositional cycles and regional correlations of upper Cretaceous rocks, southern Colorado Plateau and adjacent areas; *in* Reynolds, M. W. and Dolly E. D., eds., Mesozoic paleogeography of west-central United States: Rocky Mountain Section, SEPM, Denver, Colorado, p. 201–224.
- Page, V. M., 1968, Angiosperm wood from the Upper Cretaceous of central California. Part II: American Journal Botany, v. 55, p. 168–172.
- Page, V. M., 1979, Dicotyledonous wood from the Upper Cretaceous of central California. I: Journal of the Arnold Arboretum, v. 60, p. 323–349.
- Phillips, E. W. J., 1948, Identification of softwoods by their microscopic structure: Forest Products Research, Bulletin 22, 56 p.
- Philippe, M. and Bamford, M. K., 2008, A key to morphogenera used for Mesozoic conifer-like woods: Review of Palaeobotany and Palynology, v. 148, p. 184–207.
- Roberts, L. N. R. and Kirschbaum, M. A., 1995, Paleogeography of the Late Cretaceous of the Western Interior of middle North America—Coal distribution and sediment accumulation: U. S. Geological Survey, Professional Paper 1561, 116 p.
- Seager, W. R., and Mack, G. H., 2003, Geology of the Caballo Mountains, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Memoir 49, 136 p.
- Stevens, P. F., 2001, Angiosperm phylogeny website. Version 9, June 2008 [and more or less continuously updated since]. <http://www.mobot.org/MOBOT/research/APweb/>.
- Takahashi, K. and Suzuki, M., 2003, Dicotyledonous fossil wood flora and early evolution of wood characters in the Cretaceous of Hokkaido, Japan: IAWA Journal, v. 24, p. 269–309.
- Tidwell, W. D., Medlyn, D. A. and Thayne, G. F., 1972, Fossil palm materials from the Tertiary Dipping Vat Formation of central Utah: Western American Naturalist, v. 32, p. 1–15.
- Tidwell, W. D., Ash, S. R. and Parker, L. R., 1981, Cretaceous and Tertiary floras of the San Juan Basin; *in* Lucas, S., Rigby, K. and Kues, B. eds., Advances in San Juan Basin paleontology: Albuquerque, University of New Mexico Press, p. 307–331.
- Tomlinson, P. B., and Wilder, G. J., 1984, Systematic anatomy of Cyclanthaceae (Monocotyledoneae) – An overview: Botanical Gazette, v. 145, p. 535–549.
- Tomlinson, P. B., Horn, J. and Fisher, J., 2011, The anatomy of palms: Arecaceae - Palmae. Oxford, Oxford University Press, 276 p.
- Upchurch, G. R., Jr. and Dilcher, D. L., 1990, Cenomanian angiosperm leaf megafossils, Dakota Formation, Rose Creek Locality, Jefferson County, southeastern Nebraska: U. S. Geological Survey, Bulletin 1915, p. 1–55.
- Upchurch, G. R., Jr. and Mack, G. H., 1998, Latest Cretaceous leaf megafossils from the Jose Creek Member, McRae Formation of New Mexico. New Mexico Geological Society Guidebook 49, p. 209–222.
- Upchurch, G. R., Jr. and Wolfe, J. A., 1993, Cretaceous vegetation of the Western Interior and adjacent regions of North America; *in* Kauffman, E.G., and Caldwell, W.G.E., eds., Cretaceous evolution of the Western Interior basin: Geological Association of Canada, Special Paper 39, p. 243–281.
- Upchurch, G. R., Mack, G. H. and Wheeler, E. A., 2003, Late Cretaceous fossil forests from southcentral New Mexico: Abstracts Botany 2003, Mobile, Alabama, p. 67.
- Upchurch, G.R., Otto-Bliesner, B.L., and Scotese, C.R., 1999, Terrestrial vegetation and its effects on climate during the latest Cretaceous; *in* Barrera, E., and Johnson, C.C., eds., Evolution of the Cretaceous ocean-climate system: Geological Society of America, Special Paper 332, p. 407–426, 434–436.
- Weber, R., 1972, La vegetación maestrichtiana de la Formación Olmos de Coahuila, México: Boletín de la Sociedad Geológica Mexicana, v. 33, p. 5–19.
- Wheeler, E. A., 2011, Insidewood – A web resource for hardwood anatomy: IAWA Journal, v. 32, p. 199–211.
- Wheeler, E. A. and Lehman, T. M., 2000, Late Cretaceous woody dicots from the Aguja and Javelina formations, Big Bend National Park, Texas: IAWA Journal, v. 21, p. 83–120.
- Wheeler, E. A. and Lehman, T. M., 2005, Upper Cretaceous–Paleocene conifer woods from Big Bend National Park, Texas: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 226, p. 233–258.
- Wheeler, E. A. and Lehman, T. M., 2009, New Late Cretaceous and Paleocene dicot woods of Big Bend National Park, Texas, and review of Cretaceous wood characteristics: IAWA Journal, v. 30, p. 293–318.
- Wheeler, E.A., and Michalski, T.C., 2003, Paleocene and early Eocene woods of the Denver Basin, Colorado: Rocky Mountain Geology, v. 38, p. 29–43.
- Wheeler, E. A., Lehman, T. and Gasson, P. E., 1994, *Javelinoxylon*, an Upper Cretaceous dicotyledonous tree from Big Bend National Park, Texas, with presumed Malvaceae affinities: American Journal of Botany, v. 81, p. 703–710.
- Wheeler, E. A., McClamer, J. and LaPasha, C. A., 1995, Similarities and differences in dicotyledonous woods of the Cretaceous and Paleocene, San Juan Basin, New Mexico, USA: IAWA Journal, v. 16, p. 223–254.
- Wolberg D. L., Lozinsky, R.P., and Hunt, A.P., 1986, Late Cretaceous (Maestrichtian-Lancian) vertebrate paleontology of the McRae Formation, Elephant Butte area, Sierra County, New Mexico. New Mexico Geological Society Guidebook 37<sup>th</sup> Fall Field Conference, p. 227–334.
- Wolfe, J. A., 1990, Palaeobotanical evidence for a marked temperature increase following the Cretaceous/Tertiary boundary: Nature, v. 343, p. 153–156.
- Wolfe, J. A. and Upchurch, G. R., Jr., 1987a, Leaf assemblages across the Cretaceous-Tertiary boundary in the Raton Basin, New Mexico and Colorado: Proceedings of the National Academy of Sciences, v. 84, p. 5096–5100.
- Wolfe, J. A. and Upchurch, G. R., Jr., 1987b, North American non-marine climates and vegetation during the Late Cretaceous: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 61, p. 33–77.



AT&SF railroad spur that was laid in 1908-1909 to aid in the construction of the Elephant Butte Dam which was completed in 1916 at Elephant Butte New Mexico, ca 1920's. This photo date from the 1920's. NMBGMR Photo Archive No. p-01116.