**A NEW LATE CRETACEOUS (CONIACIAN-MAASTRICHTIAN) JAVELINOXYLON WOOD FROM CHIHUAHUA, MEXICO**

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**SUMMARY**

We describe a new fossil wood from the San Carlos Formation (Coniacian-Maastrichtian) in Chihuahua, northern Mexico. This Malvaceae *s.l.* wood is diffuse porous, vessels are solitary and in radial multiples, simple perforation plates, small alternate intervessel pits, vessel-ray parenchyma pits that are rounded with reduced borders, septate and non-septate fibers, homocellular and heterocellular rays, and storied rays and vessel elements. These features support its inclusion within the genus *Javelinoxylon*, Malvaceae *s.l.*, which occurs in other Upper Cretaceous localities in northern Mexico (Olmos Formation) and Texas (Aguja and Javelina Formations). This San Carlos fossil wood is the earliest occurrence of storied structure in the fossil record and the earliest angiosperm record for the State of Chihuahua, Mexico.

*Key words:* Late Cretaceous, wood anatomy, Malvaceae *s.l.*, San Carlos Formation, Chihuahua, Mexico.

**INTRODUCTION**

Northern Mexico is a promising region for fossil wood studies because it can provide information about Cretaceous angiosperms at lower latitudes of the Western Interior of North America. These Mexican Cretaceous floras can be compared with floras from higher latitudes and help with developing an understanding of biogeographic variation. The formations in northern Mexico (Estrada-Ruiz et al. 2007, 2010) are located near diverse assemblages of Cretaceous angiosperm fossil woods in Texas (Wheeler & Lehman 2000, 2009).

In northern Mexico there are a large number of Late Cretaceous localities bearing a relatively high diversity of angiosperm and gymnosperm fossil woods, but only a few species have been described. Cevallos-Ferriz (1983) recognized a Late Cretaceous wood from Sonora with characters suggestive of *Canarioxylon* (later considered to be closer to *Paraphyllanthoxylon* [Gryc et al. 2009]). The upper Campanian-lower Maastrichtian strata of the Olmos Formation deposited into the Sabinas Basin, Coahuila State, Mexico, have several angiosperm woods including cf. *Paraphyllanthoxylon* (Cevallos-Ferriz & Weber 1992), and others with relationships to modern families of varying certainty (?Anacardiaceae, ?Burseraceae, Cornaceae, ?Fagaceae, cf. Lauraceae). One of the...
most important families in the region, given the number of records, is Malvaceae s.l. (Estrada-Ruiz et al. 2007, 2010).

Malvaceae s.l. (which includes Bombacaceae, Sterculiaceae, and Tiliaceae; APG III, 2009) is a family that has around 4,300 species, distributed in temperate and warm regions, and is also an important element of the tropical rainforest (Bayer & Kubitzki 2003). The fossil record of Malvaceae s.l. is diverse with a large geographic and stratigraphic span. Leaves attributed to Bombax (Cretaceous to Tertiary), Byttneriophyllum (Neogene), Cola (Late Oligocene), Sterculia (Eocene to Oligocene) and Byttneriophyllum, Dombeyopsis and Laria (Neogene) (e.g., Givulescu 1970; Kvaček & Wilde 2010; Worobiec et al. 2010) have been reported. There are also records of reproductive structures, e.g., Florissantia, Cantitilia (Eocene), Daberocarpon (Cretaceous), Sterculia (Oligocene), Byttneriopsis and Craiga (Oligocene to Miocene), Reevesia (Miocene) (e.g., Kvaček et al. 1991; Manchester 1992; Mehrota 2000; Kvaček 2006; Kvaček & Wilde 2010). Fossil woods of Malvaceae s.l. have been reported from several parts of the world including North America, Europe, Africa and Asia, see Gregory et al. (2009).

In this paper we describe a new species of Javelinoxylon from the San Carlos Formation. This record represents the earliest stratigraphic occurrence of Javelinoxylon as well as the earliest occurrence of storied structure. The identification of a new species of Javelinoxylon extends our knowledge of the Late Cretaceous flora of Mexico and offers hints on the possible relationships with floras from other localities in the Western Interior of North America during the Late Cretaceous.

Figure 1. Location of the fossiliferous outcrop. – A: Map of Mexico. – B: Map of Chihuahua state.
MATERIALS AND METHODS

The fossil wood specimens studied were collected from a single locality in an outcrop of the San Carlos Formation. The locality is within the D.E.C.A. (Daniel Eduardo/David Ernesto Carrillo Acosta) Parque Cretácico A.C., which is located approximately 55 km east of Juan Aldama town, Aldama Municipality, Chihuahua, Mexico (28° 51' 45" N and 105° 24' 05" W) (Fig. 1). The area under study has different fossiliferous outcrops that contain plants, bivalves, gastropods, ammonites, and dinosaur bones (Ernesto Carrillo, personal comm. 2010). Many of the wood specimens in the outcrop are in situ, some of the woods are in growth position and are up to 10 m long. The samples described here, however, are not in situ and are less than 16 cm long (Fig. 2).

GEOLOGICAL SETTING

Hernández-Noriega et al. (2000) mapped the area where the woods studied here were collected. These authors found that the oldest Cretaceous strata that outcrop in this area belong to the formations Las Vegas (Neocomian), Del Rio (Upper Albian–Lower
Cenomanian), and Buda (Upper Cenomanian). We found the geology in the area to be complex and requiring additional study. Overlying these Cretaceous strata there are Oligocene rhyolitic tuffs (unnamed), and Miocene polymictic conglomerates and basaltic spills, as well as wide spread Quaternary silts on the top of the sequence. According to Hernández-Noriega et al. (2000) the contact between the Buda Formation and San Carlos Formation (Coniacian-Maastrichtian) is not seen in the studied area but they show that on the top of this latter formation there are oligomictic conglomerates (unnamed).

During the paleontological prospecting within and around the D.E.C.A. Park area, the fossil woods were collected with dinosaur bones from strata of green and yellow sandstone with parallel and cross laminations and paleochannels of up to 1 m long, which here are interpreted as part of the San Carlos Formation. On the top of these sands there are conglomerates that also bear dinosaur bone remains, which correspond to those conglomerate strata on the top of the San Carlos Formation mapped by Hernández-Noriega et al. (2000). Below the fossil wood-bearing strata there are calcareous clays with abundant invertebrate fossils, including bivalves, gastropods and ammonites. A preliminary taxonomical analysis on these ammonites by Dr. González-Arreola (personal comm. 2011) and her students shows the occurrence of a Barremian-Turonian assemblage that includes Mortoniceras, Brancoceras, Prionocyclus, Coillopoceras, Acanthoceras, Acompsoceras, Romaniceras, Mammites, Pseudothurmannia, which suggests a post-Turonian age of the fossil wood-bearing strata recognized here as the San Carlos Formation.

Transverse, tangential and radial sections of wood were obtained using the standard thin section technique. The descriptions use terminology from the IAWA Hardwood List (IAWA Committee 1989). Affinities were determined by consulting the literature (e.g., Metcalfe & Chalk 1950; Détienne & Jacquet 1983; Ilic 1987, 1991), and by performing searches on InsideWood, a wood identification database web site (Inside Wood 2004-onwards; Wheeler 2011). The specimens described herein are housed in the National Paleontological Collection, Institute of Geology, Universidad Nacional Autónoma de México (UNAM).

**DESCRIPTION**

**Javelinoxylon** Wheeler, Lehman & Gasson 1994 (Malvaceae s.l.)

**Javelinoxylon deca** Estrada-Ruiz & Martínez-Cabrera, sp. nov. (Fig. 3)

**Diagnosis** — Growth rings indistinct, woods diffuse porous, vessels solitary and in radial multiples of 2–7, some vessels in clusters, simple perforation plates, alternate intervessel pits, vessel-ray parenchyma pits rounded and of a single type, axial parenchyma scanty paratracheal and apotracheal diffuse, septate and non-septate fibers, rays homocellular and heterocellular, vessel elements and rays storied.

**Description** — This description, and means of the quantitative characters, is based on two specimens.

Growth rings indistinct.

Wood diffuse porous, vessels are solitary (25%) and in radial multiples of 2 (3 [7]), oval in outline with 16.5 (9–26) vessels/mm² (Fig. 3A, B). Some vessel clusters are
also present, the vessels have a mean tangential diameter of 123 (80–200) μm, and a mean vessel element length of 226 (310–500) μm. Simple perforation plates (Fig. 3C). Vessels have abundant thin-walled tyloses (Fig. 3D) and dark contents and small alternate intervessel pits with aperture diameter of 5 (4–6) μm (Fig. 3F). Vessel-ray and vessel-parenchyma pits are rounded and with reduced borders (Fig. 3E). Vessel elements are storied in some regions. Axial parenchyma apotracheal diffuse and occasionally scanty paratracheal (Fig. 3B).

Fibers are both septate and non-septate, with thin to thick walls.

Heterocellular and homocellular rays, 1–4 cells wide, triseriate rays are common, rays are storied in some regions (Fig. 3D), homocellular rays are composed of procumbent
cells and heterocellular rays are composed of procumbent cells in the body with one row of erect cells in the margins (Fig. 3G). Multiseriate rays are 562 (216–1176) μm high and 65 (32–100) μm wide.

*Holotype designated here:* National Paleontological Collection, Institute of Geology, UNAM. IGM-PB 374 (wood specimen, c. 9 cm in diameter and c. 7 cm long). IGM-LPB 966-977 (slides with thin sections).

*Paratype:* National Paleontological Collection, Institute of Geology, UNAM. IGM-PB 584 (wood specimen, c. 1.5 cm in diameter and c. 16 cm long). IGM-LPB 978-991 (slides with thin sections).

*Etymology:* The specific epithet refers to D.E.C.A. Parque Cretácico, where the wood was collected.

*Horizon:* Upper Cretaceous, Coniacian-Maastrichtian, San Carlos Formation.

**DISCUSSION**

**Comparison to fossil plants**

The combination of characters seen in this San Carlos wood (diffuse porous, vessels solitary and in radial multiples, simple perforation plates, alternate intervessel pits, vessel-ray parenchyma pits rounded with reduced borders, septate and non-septate fibers and heterocellular rays, are found in *Paraphyllanthoxylon* and *Javelinoxylon* (e.g., Wheeler *et al.* 1994, 1995; Estrada-Ruiz *et al.* 2007; Wheeler & Lehman 2009). *Javelinoxylon deca* and *Paraphyllanthoxylon* share some characters such as diffuse porosity, simple perforation plates, alternate intervessel pits, vessel-ray parenchyma pits with reduced borders, septate fibers that lack distinctly bordered pits and heterocellular multiseriate rays (Wheeler & Lehman 2009). However, the presence of storied structure and homocellular rays in *J. deca* does not support its inclusion in *Paraphyllanthoxylon* (Wheeler & Lehman 2009; InsideWood 2010), instead these characters bring it closer to *Javelinoxylon*.

Several other Malvanean fossil woods have been described (e.g., Müller-Stoll & Müller-Stoll 1949; Beauchamp *et al.* 1973; Privé-Gill & Pelletier 1981; Crawley 2001; Wheeler & Lehman 2000), but none of these records have the combination of characteristics present in *J. deca*. The position of *Javelinoxylon* within Malvaceae *s.l.*, which includes Malvaceae, Bombacaceae, Sterculiaceae and Tiliaceae (sensu APG III 2009) is uncertain. However, Wheeler *et al.* (1994) suggested it is anatomically closer to Sterculiaceae (Sterculioideae) and Tiliaceae (Grewioideae and Tilioideae, Bayer *et al.* 1999) than to Bombacaceae and Malvaceae (Bombacoideae and Malvoideae respectively [Bayer *et al.* 1999]).

At present two species of *Javelinoxylon* have been described: *J. multiporosum* from the Javelina Formation of the Big Bend National Park, Texas (Wheeler *et al.* 1994) and *J. weberi* from the Olmos Formation in northern Mexico (Estrada-Ruiz *et al.* 2007). In addition, two other xylotypes assigned to *Javelinoxylon* were described from the Olmos Formation (Estrada-Ruiz *et al.* 2010). In the last two cases, the authors did not erect new species because there was considerable anatomical variation in samples from the Olmos Formation (also observed in *Javelinoxylon* samples from the Big Bend;
E. A. Wheeler, personal comm.) and because the small sample size of each of the Olmos Formation *Javelinoxylon* xylotypes precluded analysis to determine whether there were significant differences between the samples.

Most of the differences between the formally erected *Javelinoxylon* species, the aforementioned *Javelinoxylon* xylotypes, and *J. deca* are in quantitative characters, especially in the environmentally plastic vessel characters. The other anatomical characters of *J. deca* fall within the range of the other species/xylotypes of *Javelinoxylon*, but we believe they differ enough to justify a new species. For example, *J. deca* differs from *J. multiporosum* (Wheeler et al. 1994) and *Javelinoxylon* xylotype 2 (Estrada-Ruiz et al. 2010) in the height and width of multiseriate rays. *Javelinoxylon deca* has vessel clusters, high (up to 1.1 mm) multiseriate rays and septate and non-septate fibers, unlike *J. weberi* (Estrada-Ruiz et al. 2007), which has exclusively septate fibers and shorter rays. Vessel-ray parenchyma pits in *J. deca* are of a single type (rounded), a feature only shared with the Olmos Formation *Javelinoxylon* xylotype 2. In the other species vessel-ray parenchyma pits are of two types. We believe that the combination of vessel clusters, enlarged vessel-ray parenchyma pits that are round and with reduced borders, occurrence of both septate and non-septate fibers and higher (up to 1176 μm) and wider (up to 100 μm) rays justify erecting a new *Javelinoxylon* species, *J. deca*.

The other two records of Cretaceous woods with storied structure, one also in Malvaceae s.l. and the other in Ebenaceae, are significantly different from *J. deca*. *Wheeleroxylon atascosense* (Estrada-Ruiz et al. 2010), from the Olmos Formation, has exclusively non-septate fibers, homocellular and low rays, and vessel-ray parenchyma pits of two sizes. *Ebenoxylon deccanensis* (Trivedi & Srivastava 1982) has banded axial parenchyma and mainly solitary vessels.

**Common floristic elements in the Late Cretaceous along the Western Interior of North America**

*Javelinoxylon deca* extends the geographic distribution of this genus further west. It also extends the temporal span of this genus. As has been pointed out before (Wheeler et al. 1994; Wheeler & Lehman 2005, 2009; Estrada-Ruiz et al. 2007, 2010), it seems the southern portion of the Western Interior of North America, southern North America and northern Mexico, had floristic elements in common along the margin of the Epicontinental Sea. Specifically, the genera *Metcalfeoxylon*, *Javelinoxylon* and *Paraphyllanthoxylon* are shared between the San Juan Basin, New Mexico, and Big Bend National Park, Texas, and the Sabinas Basin, Coahuila in northern Mexico, all of which are younger than the San Carlos Formation. These floras, including those in the San Juan Basin, such as those in the Kirtland and Fruitland formations, and the Olmos Formation in the Sabinas Basin, which occupy deltaic plain positions in the Western Interior, and those in the Aguja (a coastal lowland deposits) and Javelina (an inland fluvial flood-plain deposits) formations were part of a very large fluvial system (Wheeler & Lehman 2005, 2009; Estrada-Ruiz et al. 2010). Apparently these formations are similar in floristic composition, while other formations of the same age in North American, such as Panoche (California) and McNairy (Illinois) formations differ from them and from each other (Page 1970, 1979; Wheeler et al. 1987).
Incidence of storied structure in the Cretaceous of Northern Mexico

Storied structure is generally considered highly specialized (Bailey 1924) and is uncommon in fossil woods from the Late Cretaceous (Wheeler & Baas 1991). Clearly, in northern Mexico during the Late Cretaceous the incidence of this feature was high; at least 5 species with storied structure have been described for Mexican Cretaceous communities. The incidence of storied structure is more common in the Tertiary and increases through the Pliocene (Wheeler & Baas 1993). Bailey (1923) suggested that storied structure is more prevalent in species with short fusiform cambial initials and tends to occur in more derived angiosperms. Other authors (e.g., Carlquist 2001) believe that there is no clear quantitative evidence for this phyletic trend and that the claim storied structure is derived is highly speculative.

This work is an initial description of the Late Cretaceous Chihuahuan flora and therefore it may be premature to speculate about possible floristic links between the San Carlos Formation and the other floras from other geological formations of the Western Interior of North America. However, apparently Javelinoxylon was a common plant in lower latitudes of the Western Interior during the Late Cretaceous (Estrada-Ruiz et al. 2007; Wheeler & Lehman 2009).

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