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Petrified wood of southwestern Oregon: Implications for Cenozoic climate change

William S. Elliott Jr. [a,*], J. Doug Foster [b]

[a] Department of Geology and Physics, University of Southern Indiana, 8600 University Blvd., Evansville, IN 47712, USA
[b] Curator of Fossil Wood, Crater Rock Museum, 2002 Scenic Ave, Central Point, OR 97502, USA

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ABSTRACT

Over 1900 petrified wood specimens were collected from six localities spanning the Eocene to Miocene along a northeast transect parallel to the dip of the Payne Cliffs Formation and Western Cascades Group in southwestern Oregon. This study also presents new $^{40}Ar/^{39}Ar$ plateau age data for Cenozoic deposits in southern Oregon. Lower to Middle Eocene deposits yielded 305 specimens of petrified wood from sandstones and conglomerates of the basal part of the Payne Cliffs Formation with only 6% of dicotyledons exhibiting distinct growth rings and none having ring porous or semi-ring porous wood. Middle Eocene exposures just stratigraphically above the first locality produced 278 specimens from the lower to the middle part of the Payne Cliffs Formation, with 66% of the dicotyledons exhibiting distinct growth rings. Two specimens of *Palmoxylon* were also collected from sediments at this locality. An Upper Eocene exposure produced 792 petrified wood specimens from volcaniclastic sediments with 88% of the dicotyledons exhibiting distinct growth rings. Sediments at this locality also produced one specimen of *Cibotium oregonensis* (Oregon tree fern) and several specimens of *Palmoxylon*. Middle Oligocene deposits yielded 218 petrified wood specimens from volcaniclastic sediments of the middle part of the Western Cascades Group with 97% of the dicotyledons exhibiting distinct growth rings. An Upper Oligocene exposure yielded 254 specimens from volcaniclastic sediments of the upper part of the Western Cascades Group with all dicotyledons exhibiting distinct growth rings and 59% having ring porous or semi-ring porous wood. Further, this study establishes a $^{40}Ar/^{39}Ar$ plateau age date of 24.09 ± 0.24 Ma from plagioclase crystals in a tuffaceous sandy to pebbly siltstone at this locality. Finally, Lower Miocene rocks yielded 101 specimens, including 20 dicotyledons, of which 70% were ring porous or semi-ring porous, with most specimens consisting of gymnosperms. The increase over time in the percentages of dicotyledon specimens with distinct growth rings and with ring porous and semi-ring porous wood from this study suggests an overall climatic shift from tropical (Early Eocene) to cool temperate (Early Miocene) in southwestern Oregon. These results are consistent with a similar climatic shift evidenced by paleoecological reconstructions for the Eocene to Miocene of the John Day Fossil Beds in central Oregon.

1. Introduction

Petrified wood often contains detailed preservation of cellular structure and results from a very complex fossilization process (Leo and Barghoorn, 1976; Hesse, 1989; Matysová et al., 2010). Typically, petrified wood forms by permineralization, a process in which the pore spaces of the wood are filled with mineral precipitates (most often silica), followed by slow replacement of the remaining organics by mineral constituents. This process is enhanced by the presence of volcanic detritus that often is the source of silica-rich fluids that result in silicification of the wood (Matysová et al., 2010; Ballhaus et al., 2012). Regardless of the processes involved in the formation of petrified wood, well preserved specimens provide an opportunity to study the petrified wood's vascular system and growth rings, as well as details of its cellular structure.

Specifically, recent studies of petrified wood have focused on the temporal occurrences of genera and/or identification of new genera (e.g. Singleton, 2008; Hickey et al., 2011) and their significance to the evolution of land plants (e.g. Manchester and Wheeler, 1993; Stewart and Rothwell, 1993; Herendeen et al., 1999; Wheeler and Michalski, 2003; Wheeler et al., 2006). Additionally, there have been many studies that have used the detailed preservation of tree ring structures in petrified wood to reconstruct palaeotemperature, palaeoecology, and/or palaeoclimate (Chadwick and Yamamoto, 1984; Creber and Chaloner, 1985; Ash and Creber, 1992; Keller and Hendrix, 1997; Francis and Poole, 2002; van Poole and Bergen, 2006; Youngdonga et al., 2006; Brea et al., 2011; Gulbranson and Ryberg, 2013). These studies provide new insights into seasonality and palaeoclimate, as well as palaeoecological interpretations when other palaeobotanical information, such as leaf fossils, is not present.

* Corresponding author. Tel.: +1 812 228 5053; fax: +1 812 465 1052.
E-mail address: wselliott@usi.edu (W.S. Elliott).

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Previous studies in Oregon have focused on palaeobotanical studies of the Clarno Formation (Middle Eocene to Lower Oligocene) in central and northeastern Oregon (Chaney, 1948; Gregory, 1970, 1972, 1976; Manchester, 1981; Wheeler and Manchester, 2002; Wheeler et al., 2006), the John Day Formation (Oligocene to Miocene) of central Oregon (Manchester and Meyer, 1987; Retallack and Bestland, 1996; Manchester, 2000), the Little Butte Volcanic Series (Oligocene to Miocene) in Linn and Lane Counties, Oregon (Eubanks, 1960; Gregory, 1968; Retallack et al., 2004), and the Succor Creek Formation (Miocene) of Malheur County, Oregon (Eubanks, 1966). In contrast, little work has been conducted on plant fossils and petrified wood in southwestern Oregon.

The goals of this paper are the following: (1) to provide the results of a detailed study of petrified wood from six localities spanning the Eocene to Miocene in southwestern Oregon; (2) to document changes in forest ecology observed from petrified wood and its implications for Cenozoic climate change; (3) to compare the petrified wood occurrences in southwestern Oregon to the petrified wood of similar aged deposits in North America; and (4) to focus on the importance of using petrified wood to reconstruct palaeoecological systems through time, and in supplementing other palaeobotanical data, such as fossil leaves. In addition, this paper presents new ^{40}Ar/^{39}Ar plateau age data for Cenozoic deposits in southern Oregon. Finally, this study also provides new insights into the silicification process of wood in volcaniclastic settings.

2. Geologic setting

The Klamath Mountains are an elongated north-trending geological province that occupies approximately 19,000 km^2 in southwestern Oregon and northern California. The Klamath Mountains are made-up of numerous terranes that accreted during the Antler (Devonian), Sonoman (Permian to Late Triassic), and Nevadan (Jurassic to Early Cretaceous) orogenies (Mortimer and Coleman, 1985; Irwin, 1994). The Hornbrook Formation (Upper Cretaceous) rests unconformably on the crystalline rocks of the Klamath Mountains, consisting of a sequence of dominantly marine clastic sedimentary rocks about 1300 m thick exposed along the northeastern margin of the Klamath Mountains.

The Hornbook Formation is overlain unconformably by the Payne Cliffs Formation (Eocene) in the Bear Creek Valley of southwestern Oregon and by the Colestin Formation (Upper Eocene to Oligocene) in the Cottonwood Creek Valley of northern California. The Payne Cliffs Formation is 800 to 1000 m thick and consists of conglomerates and sandstones with subordinate amounts of siltstone and mudrock (McKnight, 1971, 1984). In the Siskiyou Pass area of southwestern Oregon and northern California, the Colestin Formation is dominated by volcaniclastic sediments (Carlton, 1972; Bestland, 1985, 1987). The lateral and vertical facies relationships between the Payne Cliffs and Colestin Formations are poorly constrained.

The Colestin Formation and its unnamed equivalents in the Bear Creek Valley are overlain by the Roxy Formation (Upper Oligocene to Lower Miocene), which is composed of vesicular basalt flows, volcanic breccias, volcaniclastic siltstones, shales, and conglomerates, with subordinate amounts of fine-grained, planar stratified, volcaniclastic sandstones and siltstones (Vance, 1984). The Colestin and Roxy Formations are approximately 1550 m thick in southwestern Oregon and northern California. The Roxy Formation is overlain by the Wasson Formation (Lower Miocene) which is composed of ash-flow tuffs, with interlayers of lavas and fluvial deposits (Vance, 1984). The Heppsie Andesite (Miocene) sits above the Wasson Formation. The Colestin, Roxy, Wasson, and Heppsie Formations, as well as unnamed units in the northern part of Bear Creek Valley, are collectively referred to as the Western Cascades Group.

Petrified wood is common in Cenozoic sedimentary and volcaniclastic rocks of Jackson County, Oregon. Six sampling sites spanning the Eocene to Miocene were established roughly along a northeast transect across exposures of rocks of the Payne Cliffs Formation and overlying Western Cascades Group (Figs. 1 and 2). SVE (Sams Valley East) and SVW (Sams Valley West) sampled the lower part of the Payne Cliffs Formation (Lower to Middle Eocene). Sampling locality DC (Dry Creek) occurs in the upper part of the Payne Cliffs Formation consisting of volcaniclastic sediment. The age of this locality is constrained based upon an andesite cobble that yielded a radiometric age date of 42.55 ± 2.05 Ma (Fig. 3A, Table 1). Additionally, DC occurs stratigraphically below the tuff of Bond Creek that has been dated previously at 34.9 ± 1.0 Ma (Fiebelkorn et al., 1983). Thus, the sediments exposed at locality DC are younger than 42.55 ± 2.05 Ma, but older than 34.9 ± 1.0 Ma, placing it in the Late Eocene (Walker et al., 2013).

Locality EP (Eagle Point) occurs stratigraphically above the tuff of Bond Creek and is constrained by a K/Ar radiometric age date of 29.5 ± 0.3 Ma from tuffaceous siltstone (Wiley and Smith, 1993). This places the stratigraphic succession at EP in the Lower Oligocene (Walker et al., 2013). The age of the volcaniclastic sediments at locality RT (Round Top) is constrained by several radiometric dates. Specifically, tuffaceous siltstone at RT yielded ^{40}Ar/^{39}Ar plateau ages from plagioclase of 24.09 ± 0.24 Ma and 24.38 ± 0.24 Ma (Fig. 3B, C; Table 1). Additionally, a basaltic andesite lava flow sitting stratigraphically above these tuffaceous units at locality RT provided a ^{40}Ar/^{39}Ar plateau age of groundmass of 23.25 ± 0.24 Ma (Fig. 3D; Table 1). This constrains the age of the sediments at RT to the Late Oligocene (Walker et al., 2013). The youngest exposures (Miocene) at the BF (Butte Falls) locality are stratigraphically positioned in the upper part of the Western Cascades Group (Smith et al., 1982; Wiley et al., 2011).

3. Methods

Over 1900 petrified wood specimens were collected from six sampling sites in Cenozoic sedimentary and volcaniclastic rocks exposed along a northeast transect in Jackson County, Oregon. The collected samples were cleaned thoroughly by wire brushing the surfaces with soap and water to better expose the preserved vascular structures of the wood, and, as needed, transverse surfaces were ground flat or cut with a rock saw and polished. Specimens were excluded from this study if they were too small in diameter to show mature stem characteristics or if they showed significant modification due to premineralization degradation or overburden pressure distortion (e.g. Wiemann et al., 1999). Most petrified wood specimens were identified by examining vascular structures on transverse surfaces with a 20× hand lens (Barefoot and Hankins, 1982; Hoadley, 1990); selected specimens were cut into billets, thin-sectioned, and identified by examining their cellular structures on radial, tangential, and transverse surfaces through a petrographic microscope. The Crater Rock Museum in Central Point, Oregon is the current repository for the petrified wood specimens used in this study, except for site BF, where 34 specimens were not retained in collections, including 27 *Taxodioxylon*; 5 *Quercinium* (live oak); and 2 *Acer* (maple)-like specimens.

Accurate identification of many petrified wood genera requires microscopic analysis of cellular structures, while this study primarily relied on 20× analysis of vascular structures; accordingly, a more general terminology is employed: appending the suffix "-like" to extant, generic comparables; i.e., *Juglans* (walnut)-like (Daniels and Dayvault, 2006). Three notable exceptions are for the extinct genera *Platanoxylon* (fossil sycamore), *Quercinium* (fossil live oak), and the form genus *Taxodioxylon* (that may include fossil *Metasequoia*, *Sequoia*, and/or bald cypress), representative samples of which were identified by petrographic analysis. For example, petrographic analysis of the cellular structures of three representative *Platanus*-like specimens from two different sites (DC-81, DC-358, and EP-111) determined that all three belonged to the extinct genus of sycamore *Platanoxylon*.

The age of the sediments from which petrified wood samples were collected was determined by plotting the location of the sampling sites on published geologic maps. In addition, geologic field work by