Fossil plants of the Eocene Clarno Nut Beds

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INTRODUCTION

Visitors to the Clarno Unit of John Day Fossil Beds National Monument (Figure 1) in north-central Oregon are likely to be most impressed by the present-day landscape and vegetation. Craggy rocks spotted with clumps of grass, sagebrush, and occasional juniper trees provide a rather stark setting for picnic tables. However, fossils from these same rocks show that a very different environment prevailed in the vicinity some 48 million years ago. Eocene fossils in the Clarno Formation include fan palms, cycads, magnolias, grapes, and a diversity of other plants, many of which are suggestive of a tropical rain forest.

The Clarno Formation is a sequence of volcanic flows and intrusions, mudflows, and tuffs sandwiched between marine Cretaceous sediments and the late Oligocene to Miocene John Day Formation. The age of the Clarno Formation, based upon potassium-argon radiometric dates (Enlows and Parker, 1972), ranges from Eocene to early Oligocene. Although numerous fossil plant localities are known in the Clarno Formation (Hergert, 1961), few have been studied in rigorous detail.

A large assemblage of middle Eocene plants occurs in the type area of the Clarno Formation, just west of Camp Hancock (Figure 1), on the northern border of John Day Fossil Beds National Monument. The site is called the "Nut Beds" because of the fossil fruits and seeds ("nuts") which occur there. A popular account of the petrified fruiting structures is given by Bones (1979). The Nut Beds is an unusual fossil locality because several kinds of plant parts, including fruits, seeds, woods, leaves, flowers, and pollen, are preserved there. As a result, the locality has become the focus of an intensive program of paleobotanical research (Scott, 1954, 1956; Scott and Barghoorn, 1956; Scott and others, 1962; Manchester, 1977, 1979, 1980a).

The Oregon Museum of Science and Industry (OMSI) has sponsored field research at the Nut Beds locality in cooperation with the National Park Service since 1976. Recent excavations have yielded exciting new material including a large collection of fossil leaves. The identification of these remains is an ongoing process. This paper is a brief introduction to the flora based on previous publications and recent research.

GEOLOGY AND AGE

The Nut Beds deposit (Figures 2 and 3) is comprised of tuffaceous siltstones, sandstones, and conglomerates which appear to represent stream channel and levee sedimentation. The deposit crops out in a limited area of less than 0.5 km² and is approximately 10 m thick. Figure 4 is a generalized stratigraphic column for the Nut Beds, based on measurements from the central face of the exposure. The sequence grades from alternating layers of siltstone and sandstone near the base

Figure 1. Geologic map of the Clarno area. The Nut Beds deposit is located adjacent to Camp Hancock on the northern border of the National Monument. (Modified from Baldwin, 1976)

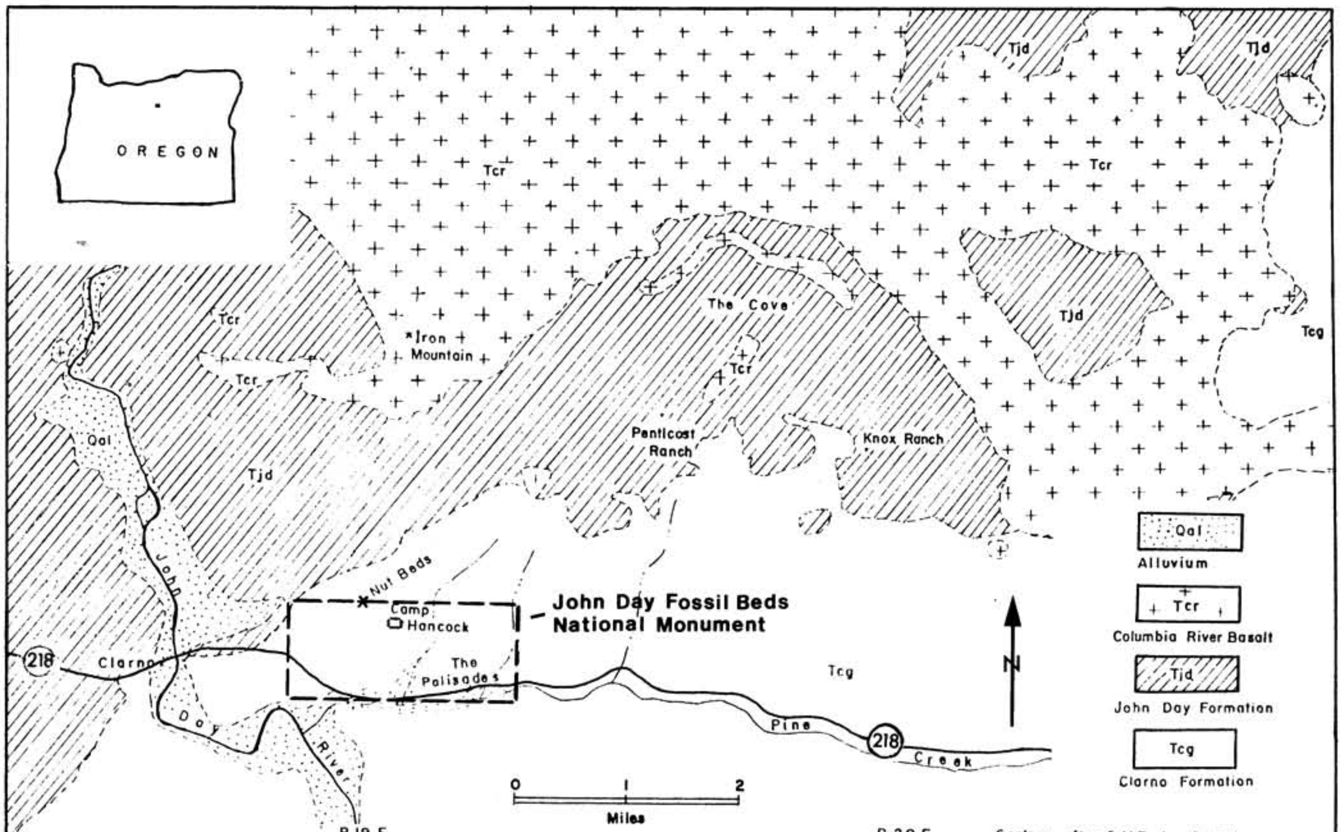


Figure 2. Northwesterly view of the Nut Beds. The deposit crops out in the faces labeled 1 through 4.

Figure 3. Profile view of Face 3 in the Nut Beds. Students are excavating fossil leaves from the basal siltstones.

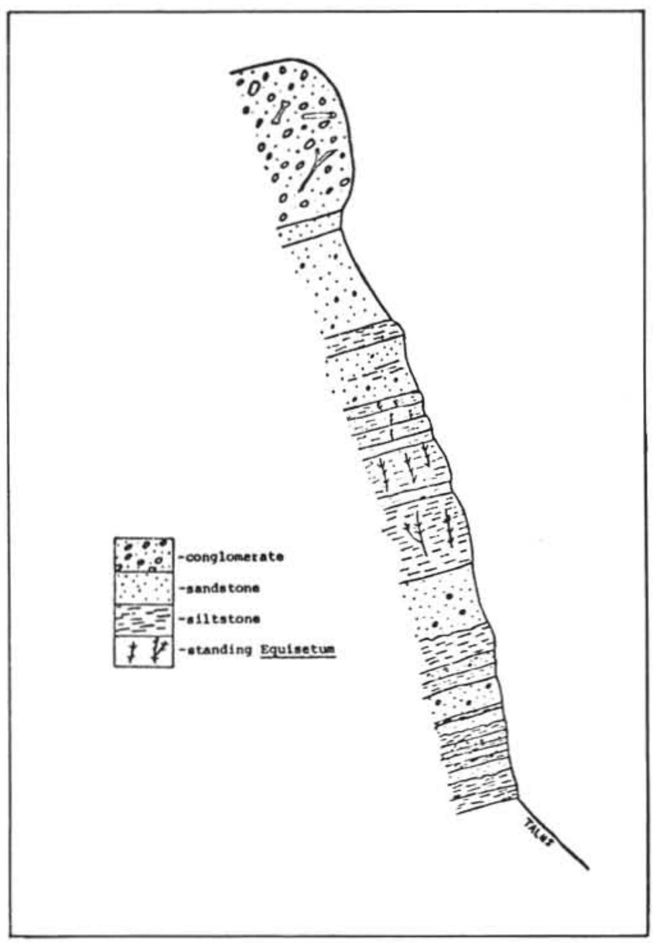


Figure 4. Generalized stratigraphic column for the Nut Beds based on measurements from Face 3. Section measures 10 m in thickness.

to coarse sandstone and conglomerate at the top. The fine-grained sediments of the basal portion contain rooted horsetails and ferns, indicating shallow-water conditions and relatively rapid burial. The upper conglomerates, which contain disarticulated vertebrate bones and waterworn woods, appear to represent stream-channel deposition. Plant remains are found throughout the horizontal and vertical extent of the exposure.

A potassium-argon date of 34.0 million years based on tuff from the Nut Beds vicinity was reported by Evernden and James (1964). This date is questionable, however, because the tuffs of the Nut Beds are highly altered, and it is unlikely that even a freshly broken sample would be suitable for accurate dating. Fossil mammal correlations suggest that the Nut Beds strata are middle Eocene, or about 48 million years old (Stirton, 1944; Hanson, 1973). Based on intensive field work in the Camp Hancock area, C. B. Hanson (1980, personal communication) suggests that the Nut Beds represent a portion of the lower Clarno Formation which was uplifted by folding prior to deposition of the Palisades mudflows and the upper Clarno tuffs.

FOSSIL LEAVES

Research in progress on the Clarno Nut Beds flora includes an intensive investigation of leaf remains. Although leaf impressions are abundant in the Nut Beds, they have received little attention in the literature. Exceptionally well-preserved specimens, some even retaining cuticle, occur in a few siltstone strata at the base of the section (Figure 3). Unfortunately, the strata are heavily fractured, making it virtually impossible to remove a leaf fossil in a single slab of rock. As each fragment is removed from the layer, its position must be marked so that adjoining parts of the same fossil may be glued together. Thus, the removal of leaves is a delicate and time-consuming operation. However, with the help of student teams, about 80 genera have been recovered since 1974. A few of the identified specimens are shown in Figures 5 to 11.

FLORAL COMPOSITION

At least 140 different genera are represented in present collections from the Nut Beds. This conservative estimate includes 100 genera of fruiting structures, 80 genera of leaves, and 40 genera of woods which are distinguishable in present collections of the Smithsonian Institution (T. J. Bones collection) and OMSI. Preliminary palynological work has also yielded several genera of pollen and spores. At this point in study, it has been possible to identify 49 taxa belonging to modern families or genera with a high level of certainty. These identifications are listed in Table 1.

Identification of the Nut Beds fossils is based upon rigorous comparisons with modern plants. When a fossil is found to exhibit a suite of characteristics diagnostic of a particular modern taxon, it may be assigned to that family or genus. For example, fossil acorns from the Nut Beds (Bones, 1979) are sufficiently distinctive to justify their identification with the modern genus *Quercus*. Sometimes a particular fossil may be matched equally well by more than one modern genus. In such cases, the fossil may be assigned to a special organ genus. For example, the organ genus *Anonaspermum* (Reid and Chandler, 1933) is used for fossil seeds of the Anonaceae because it is difficult to distinguish modern genera of the family based on seeds. In addition, some of the fossils clearly represent extinct genera for which new names must be formed. For example, the genus *Chattawaya* was erected to accommodate an extinct wood of the Sterculiaceae from the Nut Beds (Manchester, 1980a). Because of both the large number of modern plants with which comparisons must be made and difficulties in determining affinities of extinct forms, a large proportion of the Nut Beds taxa remain unidentified. Therefore, the floral list given in Table 1 excludes a large number of taxa whose affinities are as yet unknown.

Horsetails and ferns are fairly common throughout the Clarno Formation. *Equisetum clarnoi* (Brown, 1975) is especially abundant in the Nut Beds. The ferns *Dennstaedtiopsis aerenchymata* and *Acrostichum preaureum* have been recognized from silicified petioles. These species were reported earlier from another Clarno locality (Arnold and Daugherty, 1963, 1964). Two additional fern genera as yet unidentified are represented by leaf imprints in the Nut Beds.

Several frond portions similar to the modern cycad genus *Dioon* have been recovered from the Nut Beds (Figure 5). These represent the same species reported by Chaney (1937) from the Palisades mudflows. Other gymnosperms present in the assemblage include *Ginkgo,* known from a single wood sample (Scott and others, 1962) and a few leaf impressions (Figure 6), *Pinus* (pine), represented by wood and pollen, and a taxodiaceous wood, possibly *Sequoia* or *Metasequoia.*

The bulk of the flora is comprised of angiosperms, or flowering plants. The most abundant remains in this category include members of the following families: Palmae (palm family, Figure 7), Juglandaceae (walnut family, Figure 8), Menispermaceae (moonseed family, Figure 10), Lauraceae (avocado family), Sabiaceae (*Meliosma* family, Figure 11) and Platanaceae (sycamore family).

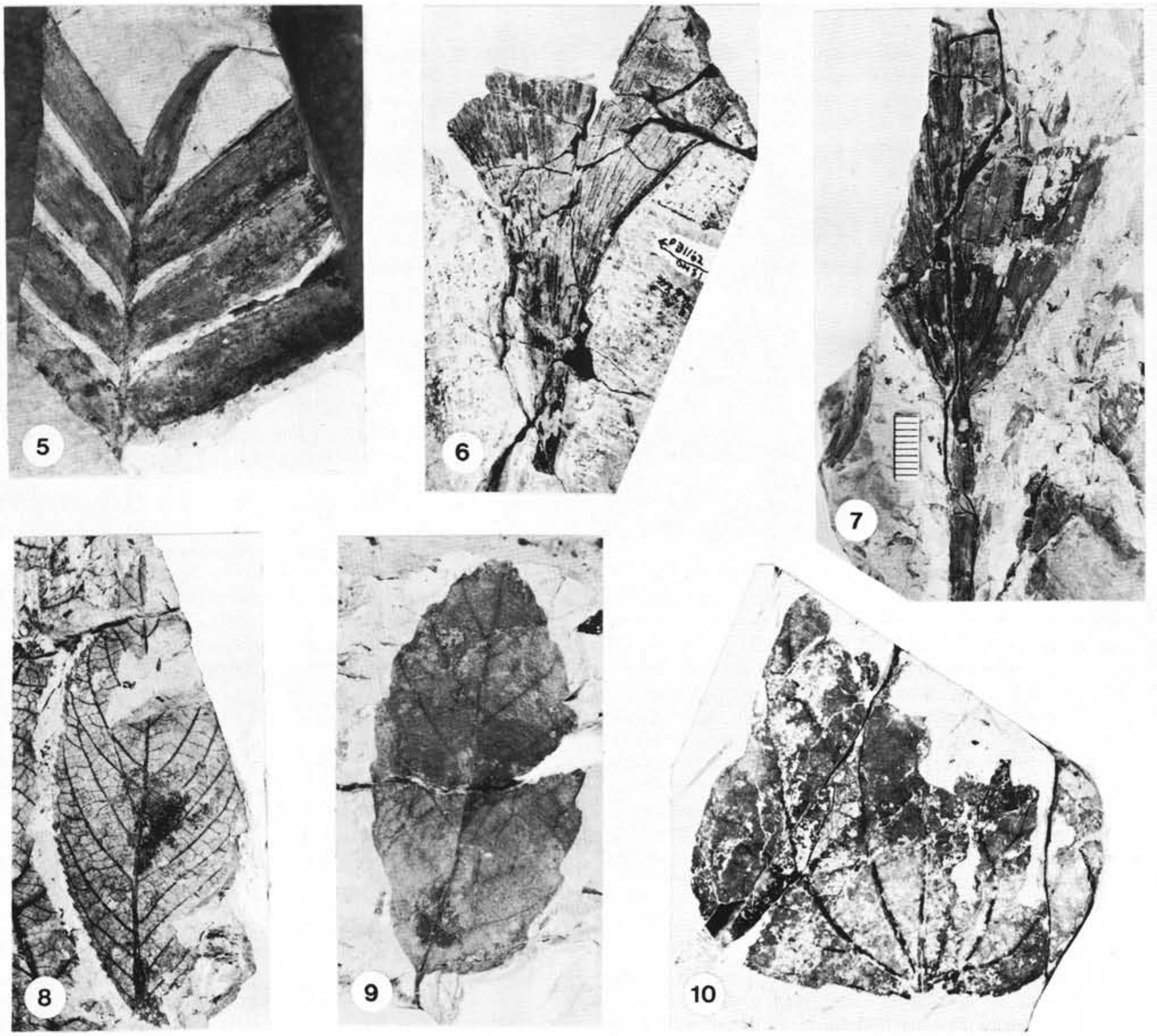
New identifications apply to two of the taxa figured by Bones (1979). Fruiting heads formerly thought to be *Altingia* (Bones, 1979, plate 2, Figure 5) have been shown to be *Platanus* (Manchester and Dilcher, 1980). Specimens figured as unidentified endocarps by Bones (1979, plate 6, Figures 1 and 2) have since been identified as *Tapiscia.*

ENVIRONMENTAL CONSIDERATIONS

The arid, semidesert conditions prevailing in the Clarno Basin today contrast strikingly with the environment reflected by the middle Eocene Nut Beds flora. Analysis of the floral assemblage indicates that the region was tropical or subtropical in the mid-Eocene. Two independent approaches have been used to assess the paleoenvironment: (1) the distribution and climatic requirements of related modern taxa, and (2) analysis of leaf form and correlation with environment.

A large portion of the identified taxa of the Nut Beds flora (Table 1) are chiefly tropical in their distribution today. *Dioon,* Palmae, *Alangium, Tapirira, Astronium,* Icacinaceae, Anonaceae, Menispermaceae, *Meliosma, Engelhardia, Castilla, Tetrapteris,* Sterculiaceae and Lauraceae are families and genera whose present-day species are mostly or exclusively restricted to tropical regions of Central and South America, southeast Asia, and (more rarely) Africa. The occurrence of these taxa in the Nut Beds suggests that the climate was warm, moist, and equable. In addition, there is a relatively high proportion of vines, lianas, and epiphytes (Vitaceae, Icacinaceae, *Tetrapteris, Hydrangea,* and others). These growth habits are most prevalent in tropical rain forests. Some of the identified genera, such as *Pterocarya* and *Ginkgo,* are absent from subtropical and tropical environments today. Presumably, the modern species of these genera have ecological tolerances which differ from those of the fossil species.

Analysis of leaf physiognomy also supports the interpretation that the Nut Beds flora was a tropical rain forest. This method of paleoclimate determination is based upon the observation that various foliage characteristics of modern



Figures 5-10. Fossil leaves from the Nut Beds. Natural size. 5. Dioon, *a cycad common in the Clarno Formation.* 6. Ginkgo, *the maidenhair tree.* 7. Sabalites, *a small fan palm frond.* 8. Pterocarya, *leaflet of the walnut family.* 9. Quercus, *oak.* 10. cf. Odontocarya, *a member of the moonseed family.*

floras, such as leaf size and margin type, tend to reflect the environment of growth. Species growing under tropical rain forest conditions typically possess large leaves with entire margins, while species adapted to temperate forests tend to have small leaves with serrate margins (Bailey and Sinnott, 1916; Wolfe, 1971). Forty-five of the 75 dicot leaf species recognized in the Nut Beds (considering unidentified as well as identified species), or about 60 percent, are entire margined (M. Muldoon, 1980, unpublished investigation). This figure falls well within the range of values suggested by Wolfe (1969, 1971) for paratropical rain forests, such as those growing today in lowland Taiwan. In contrast, temperate forests, such as those of Oregon's Willamette Valley, typically average from 10 to 40 percent entire-margined species. The high proportion of Nut Beds species with large leaves is also indicative of warm mesic conditions.

The suggestion of subtropical to tropical rain forest is also supported to some degree by wood structure. Most of the woods exhibit diffuse porosity, a condition which is most prevalent in tropical environments. However, the occurrence of distinct growth rings in most of the woods suggests definite seasonality.

EVOLUTIONARY IMPLICATIONS

The angiosperms, or flowering plants, are the most recently evolved major group in the plant kingdom, yet they have become the dominating element in most of the world's present-day vegetation. The initial evolutionary radiations of the angiosperms are recorded in upper Lower to lower Upper Cretaceous rocks (Hickey and Doyle, 1977). Early angiosperm floras are difficult to interpret because most of the taxa represent extinct groups whose relationships with modern families have been obscured by evolution. Successively younger floras become easier to interpret as the lines leading to modern genera and species become recognizable.

Investigation of the Nut Beds flora provides an opportunity to assess the evolutionary status of selected angiosperms

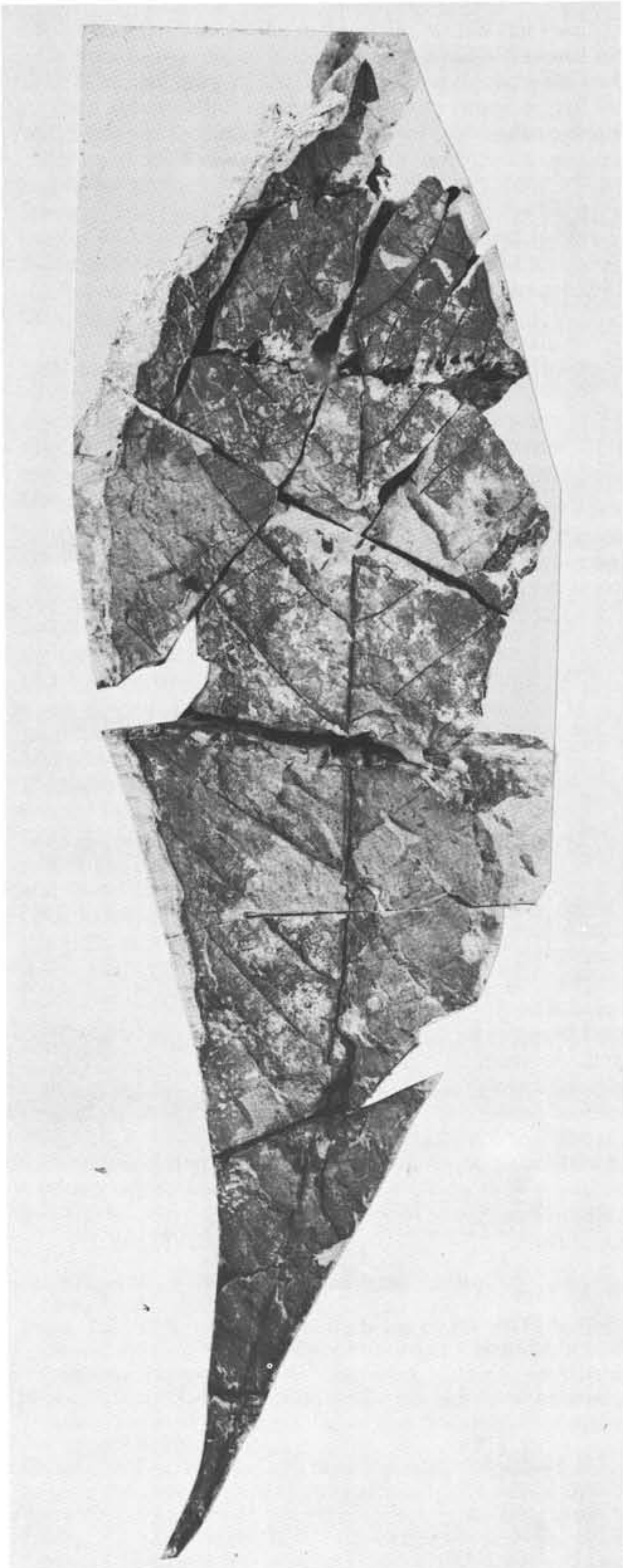


Figure 11. Meliosma. *A common leaf type in the Clarno Formation. Today this genus occurs in tropical Asia and Central and South America. Natural size.*

during the Eocene, which was about midway between the initial radiation of angiosperms and the present day. Due to the availability of several organ types in the Nut Beds, it is possible to conduct multiple-organ investigations of modernization in various angiosperm taxa during the middle Eocene.

As is evident from the foregoing sections of this paper, in which many of the fossils have been assigned to extant genera, the Nut Beds included many taxa which were well advanced along modern lines. This may give a false first impression of the flora, however. The Nut Beds flora actually shows a range in levels of modernization, including nearly identical forms, modern species, and forms belonging to extinct genera.

Most of the Nut Beds taxa appear to be extinct at the species level. One possible exception is a species of *Meliosma* represented by leaves, wood, and fruits from the Nut Beds. Based on careful analysis of these organs, the fossil species seems to be conspecific with the living species, *Meliosma simplicifolia* of Asia (Manchester, 1980b).

Although many of the Nut Beds taxa can be placed in modern genera (*Quercus, Platanus, Juglans, Vitis,* and others), it is frequently demonstrable that extinct species, or even subgenera, are represented. For example, Scott (1954) showed that the walnut, *Juglans clarnensis,* was an extinct species intermediate in fruit morphology between two modern sections of the genus *Juglans*. The Nut Beds walnut bore nutshells resembling those of the section *Rhysocaryon* but seeds characteristic of section *Cardiocaryon*.

Several extinct genera are known from the Nut Beds, including *Odontocaryoidea, Chandlera, Palaeonyssa* (Scott, 1954), *Langtonia* (Bones, 1979), *Triplochitioxylon* (Manchester, 1979), and *Chattawaya* (Manchester, 1980a). Some of these, such as *Langtonia,* appear to represent genera with no direct modern descendants. Others, such as *Odontocaryoidea* and *Triplochitioxylon,* may represent lineages which gave rise to similar but distinct genera that are still living today, such as *Odontocarya* and *Triplochiton*.

From this preliminary analysis, it is apparent that the elements of the Nut Beds flora varied in their evolutionary status. Some families, such as the Sabiaceae, Fagaceae, and Juglandaceae, are represented by species which are assignable to present-day genera, suggesting that they existed in the Eocene much as they do today and that relatively little post-Eocene evolution has occurred. Other families, such as the Menispermaceae and Sterculiaceae, are characterized by species which must be placed in extinct genera, suggesting that the morphological features characteristic of modern genera were still evolving in the middle Eocene.

Current research focuses on plant families which are represented in the Nut Beds assemblage by two or more organ types. It is of interest to know which organs in a given family or genus were more advanced and which were less advanced (relative to the condition in modern species) in the Eocene. This type of research requires intensive morphological and anatomical comparison with the living species of the family or genus under consideration.

One of the present areas of study involves the sycamore family, Platanaceae, which is represented in the Nut Beds assemblage by wood, leaves, and infructescences (fruiting structures) (Manchester and Dilcher, 1980). Since only one species of each organ is present in the large array of fossils from the Nut Beds, it is assumed that the organs probably represent the same biological genus and species. This assumption is supported by the fact that these organs also occur together in other Clarno localities. The infructescences of this plant (figured as *"Altingia"* in Bones, 1979) are common in the Nut Beds. They consist of fruiting heads or "seed balls" and were borne in strings of up to five, as in several modern species

Table 1. List of plant remains identified from the Clarno Nut Beds.

Family	Genus	Common name or comment	Organs represented
Equisetaceae	*Equisetum*	Horsetail	Stem, rhizome, cone
Dennstaedtiaceae	*Dennstaedtiopsis*	Fern	Petiole
Polypodiaceae	*Acrostichum*	Fern	Petiole
Cycadaceae	*Dioon*	Cycad	Leaf (Figure 5)
Ginkgoaceae	*Ginkgo*	Maiden hair tree	Wood[2], leaf (Figure 6)
Pinaceae	*Pinus*	Pine	Wood, pollen
Taxodiaceae	undetermined	Sequoia family	Wood
Palmae	*Palmoxylon*	Palm	Wood
	Palmocarpon	Palm	Fruit[6]
	Sabalites	Palm	Leaf (Figure 7)
Alangiaceae	*Alangium*	Tropical tree	Fruit[6]
Anacardiaceae	*Tapirira*	Cashew family	Wood[3]
	Astronium	Tropical tree	Wood
	Dracontomelon	Tropical tree	Fruit[6]
Anonaceae	*Anonaspermum*	Custard apple family	Seed[6]
Burseraceae	*Bursericarpum*	Torchwood family	Fruit[6]
Cercidiphyllaceae	*Cercidiphyllum*	Katsura tree	Wood, leaf, fruit
Cornaceae	*Mastixioidiocarpum*	Extinct genus	Fruit[1]
	Langtonia	Extinct genus	Fruit
Fagaceae	*Quercus*	Oak	Wood, fruit[6], leaf (Figure 9)
	Castanea	Chestnut	Leaf
Icacinaceae	*Paleophytocrene*	Tropical vine	Fruit[1]
Juglandaceae	*Juglans*	Walnut	Fruit[1]
	Pterocarya	Wingnut	Leaf (Figure 8)
	Engelhardia	Tropical tree	Wood, fruit[6]
Lauraceae	*Laurocarpum*	Avocado family	Fruit[1]
	Cinnamomophyllum	Avocado family	Leaf
	Ulminium	Avocado family	Wood
Leguminosae	*Tetrapleuroxylon*	Acacia family	Wood
Magnoliaceae	*Magnolia*	Magnolia	Leaf, seed[6]
Malpigiaceae	*Tetrapteris*	Tropical vine	Fruit
Menispermaceae	*Chandlera*	Extinct moonseed	Fruit[1]
	Odontocaryoidea	Extinct moonseed	Fruit[1]
	Dipoclisia?	Moonseed family	Fruit
	Tinospora?	Moonseed family	Fruit
Moraceae	*Ficoxylon*	Fig family	Wood
	Castilla	Fig family	Leaf
Platanaceae	*Platanus*	Sycamore	Wood, leaf, fruit
Rhamnaceae	*Berhamnophyllum*	Buckthorn family	Leaf
Sabiaceae	*Meliosma*	Aguacatilla	Wood, leaf (Figure 11) Fruit[6]
Sapindaceae	undetermined	Sapindus family	Seed[6]
Saxifragaceae	*Hydrangea*	Popular ornamental	Fruit
Staphyleaceae	*Tapiscia*	Bladdernut family	Seed
Sterculiaceae	*Triplochitioxylon*	Extinct tree	Wood[4]
	Chattawaya	Extinct tree	Wood[5]
Ulmaceae	undetermined	Elm family	Wood, leaf
Vitaceae	*Vitis*	Grape	Seed[6]
	Parthenocissus	Vine	Seed[1]

[1]Described by Scott, 1954.
[2]Described by Scott and others, 1962.
[3]Described by Manchester, 1977.
[4]Described by Manchester, 1979.
[5]Described by Manchester, 1980a.
[6]Figured in Bones, 1979.

of sycamore. Each of the many fruits within the fossil seed balls bore five seeds, as in the modern species *Platanus orientalis.* The similarity of the fossil wood and seed balls to the modern species of *Platanus* suggests that these organs were well advanced by the Eocene. The leaves (cover photo), on the other hand, are of an extinct type with more lobes and smaller angles of primary vein divergence than in extant *Platanus* species. The Nut Beds plant thus appears to be an extinct species with wood and fruits essentially identical to those of living species and distinctive leaves. This suggests that leaves in the Platanaceae have been more plastic, or less conservative, in their evolution than the wood and fruits.

As investigation of various organs and taxa from the Nut Beds continues, it will be possible to refine our understanding of the evolutionary status of various angiosperm families and genera at a point in time about 48 million years ago. Hopefully, this work will stimulate other workers to apply similar methodologies to the study of well-preserved angiosperm floras of other ages and in other parts of the world.

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Since 1976, four teams of high school students have been involved in the excavation of fossil leaves from the Nut Beds for this project, each student contributing numerous hours of tedious field work. Without their help, little would be known about the Nut Beds leaf flora. Special thanks are due to Scott Blanchard, Maureen Muldoon, Kris Goertz, and Jerome McFadden for their continuing assistance with the project. Elizabeth Harding aided in the interpretation of the stratigraphy by trenching and measuring critical sections in the field. Identification and interpretation of the leaves was carried out with assistance from Leo J. Hickey, Jack A. Wolfe, and David L. Dilcher. The final manuscript was reviewed by Greg Retallack. This research was funded in part by the National Science Foundation (Grant No. DEB7906837).

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Note to the reader:

The absolute age of the boundary between the John Day and Clarno Formations and the stratigraphic and structural relationships of the two formations will be discussed in an upcoming issue of *Oregon Geology* in an article entitled, "A Mafic Dike System in the Vicinity of Mitchell and Its Bearing on the Timing of Clarno-John Day Volcanism and Early Oligocene Deformation in Central Oregon," by Edward M. Taylor, Department of Geology, Oregon State University, Corvallis, Oregon. □

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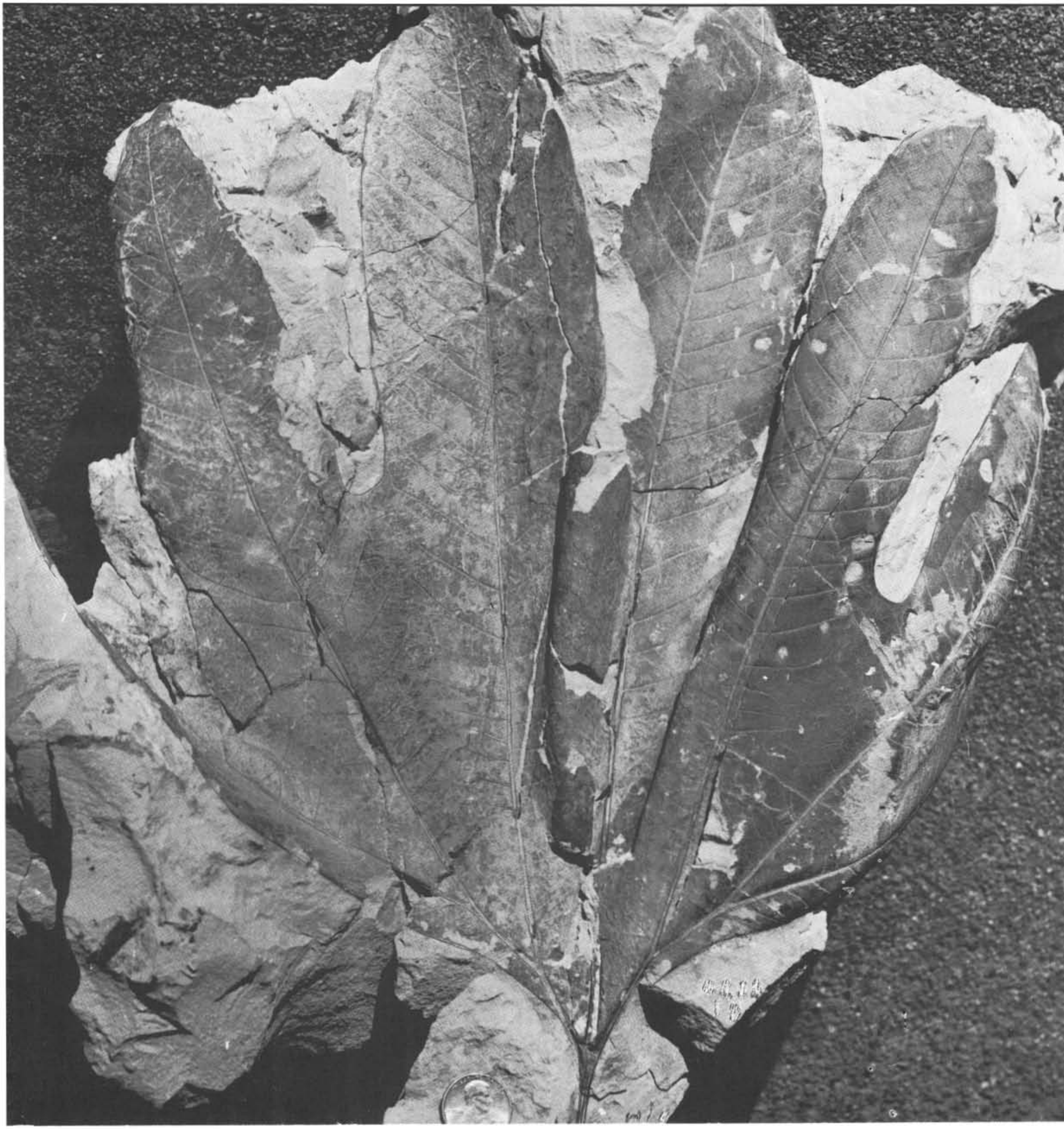

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Open-file reports assess geothermal resources of areas in central and eastern Oregon

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces the release of five new open-file reports presenting raw and interpreted data that are the results of its U.S. Department of Energy/State of Oregon-funded low-temperature geothermal-resource studies in central and eastern Oregon. The reports contain raw and interpreted geothermal-gradient data, radiometric ages of selected rocks, chemical analyses of spring and well water, calculated minimum reservoir temperatures, extensive bibliographies, and a variety of geological and geophysical maps.

Open-File Report 0-80-4, *Preliminary Geology and Geothermal Resource Potential of the Craig Mountain-Cove Area, Oregon,* presents geothermal data for the part of the Grande Ronde River basin that surrounds La Grande, Union, and Cove in eastern Oregon. Included in the 68-page text is a generalized geologic map of the La Grande area; accompanying the text is a two-color preliminary geothermal resource map (scale 1:250,000) of the study area. Price of Open-File Report 0-80-4 is $5.00.

Open-File Report 0-80-5, *Preliminary Geology and Geothermal Resource Potential of the Western Snake River Plain, Oregon,* contains geothermal data from the western portion of the Snake River Plain, including the eastern Oregon communities of Vale and Ontario. Included in the 114-page text are three audio-magnetotelluric resistivity maps (27, 14, and 7.5 hertz) of the area; accompanying the text are two two-color generalized geologic maps and a one-color total field aeromagnetic anomaly map (scale 1:62,500) and a two-color photo-lineament and complete Bouguer gravity anomaly map (scale 1:250,000)—all of the western Snake River Plain. Open-File Report 0-80-5 sells for $10.00.

The Powell Buttes area, near Bend, Prineville, and Redmond in central Oregon, is the subject of Open-File Report 0-80-8, *Preliminary Geology and Geothermal Resource Potential of the Powell Buttes Area, Oregon.* Included in the text are photo-lineament, isogradient, complete Bouguer gravity anomaly, residual gravity anomaly, and total aeromagnetic anomaly maps of the area. Accompanying the text is a two-color geologic map (scale 1:62,500) of the Powell Buttes area. Open-File Report 0-80-8 sells for $5.00.

Open-File Report 0-80-9, *Preliminary Geology and Geothermal Resource Potential of the Lakeview Area, Oregon,* presents data from the area surrounding Lakeview in southernmost central Oregon. Included in the 108-page text are photo-lineament and total field aeromagnetic anomaly maps of the area. Accompanying the text are a one-color gravity anomaly map and a two-color generalized geologic map (scale 1:62,500) of the Lakeview area. Open-File Report 0-80-9 costs $7.00. *(Continued, page 86)*

COVER PHOTO

Leaf impression of the "Clarno Sycamore" (*Platanus* sp.), a plant common in the Eocene Clarno Formation of Oregon. This specimen, measuring 14 in., was collected by Scott Blanchard from the Cherry Creek locality. Primary veins retouched. Related article begins on next page.

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