Late Eocene fossil plants of the John Day Formation, Wheeler County, Oregon

by Steven R. Manchester, Florida Museum of Natural History, PO 117800, University of Florida, Gainesville, FL 32611-7800

ABSTRACT

Fossil leaves, fruits, and seeds are described from a late Eocene lacustrine deposit in the lower part of the John Day Formation on the southern slope of Iron Mountain east of Clarno, Wheeler County, Oregon. The Whitecap Knoll locality is closely bracketed with radiometric dates and hence provides a new datum for the evaluation of floristic and climatic change in the late Eocene. The fossil-bearing shale is above the member A ignimbrite, dated 39.17 ± 0.15 Ma, and below a tuff dated 38.4 ± 0.7 Ma and is considered to be about 38.8 Ma. The plant assemblage includes an aquatic component (*Nelumbo*, *Ceratophyllum*), and a woodland component with broadleaved deciduous plants (Platanaceae, Fagaceae, Juglandaceae, Ulmaceae, Aceraceae), a few broadleaved evergreen plants (*Mahonia*, *Cinnamomophyllum*), and a few unidentified ferns but apparently no conifers. The flora lacks the diversity of broad-leaved evergreen taxa present in the middle Eocene floras of the underlying Clarno Formation, but retains a few "Clarno taxa" not known in the overlying Bridge Creek flora (*Ailanthus* and *Eucommia*). The intermediate character of this flora in comparison with middle Eocene lacustrine floras of the Clarno Formation and lower Oligocene floras of the Bridge Creek flora provides some evidence for a gradational transition from the Eocene subtropical vegetation to the Oligocene temperate forests in this region.

INTRODUCTION

Paleontologically, the John Day Formation of Oregon is probably best known for its spectacular mammalian fossils of earl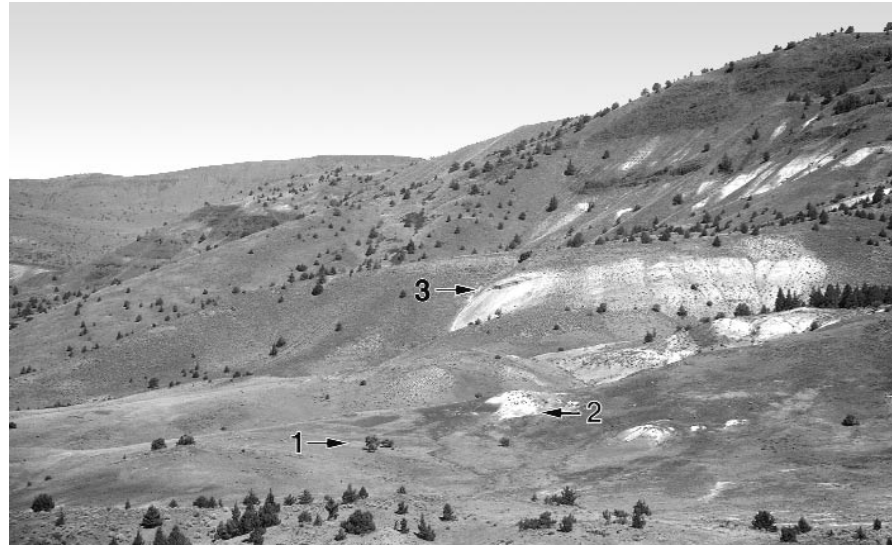y Miocene age (e.g., Cope, 1880, 1886; Thorpe 1925; Merriam, 1930; Rensberger, 1973) and the still older plant fossil assemblages of the lower Oligocene Bridge Creek flora (Chaney, 1927; Meyer and Manchester, 1997).

Figure 1. Oblique northwesterly aerial view of the south slope of Iron Mountain, showing (1) position of the lacustrine shale from which the Whitecap Knoll flora has been obtained, (2) the Whitecap Knoll locality from which the Ar/Ar date was obtained, and (3) the lacustrine shales of the Slanting Leaf Beds (Iron Mountain assemblage) of the Bridge Creek flora of the John Day Formation.

Figure 2. Students working at the Whitecap Knoll shale locality, with Whitecap Knoll in central part of the image and Slanting Leaf Beds to the far left.

However, fossils from the lowermost part of the formation, which includes late Eocene strata, have received relatively little attention. Floras of late Eocene age are known

from the John Day Formation in the Gray Butte area of Jefferson County, but the precise ages are difficult to determine because the associated volcanic rocks there are highly altered (Smith and others, 1998).

The Whitecap Knoll flora (Figures 1, 2; Bestland and Retallack, 1994) near the northern boundary of the Clarno Unit of John Day Fossil Beds National Monument in Wheeler County, Oregon, provides a rare opportunity to examine a late Eocene plant community that is well bracketed with radiometric dates. These dates indicate that the deposit and the species contained within it are approximately 38.8 million years old. This flora thus provides an important datum for purposes of correlation with less securely dated fossil localities in western North America. The Whitecap Knoll locality is situated near several other paleobotanically important sites (Figure 3), including sites of the underlying Clarno Formation, e.g., the Nut Beds (Manchester, 1981, 1994), the Hancock Canyon wood and leaf localities (Manchester, 1986), and Hancock Quarry (McKee, 1970; Manchester, 1994, p. 13); and of the overlying John Day Formation, such as the Slanting Leaf Beds[1] locality (Figure 1). The geology of this area has been reviewed by Bestland and others (1999) and Retallack and others (2000).

The climatic shift near the end of the Eocene from warm, equable conditions to cooler, more seasonal conditions has received much attention (e.g., Chaney, 1948; Retallack, 1992; Wolfe, 1992; Smith and others, 1998). The middle Eocene Clarno Nut Beds flora (about 44 million years old) has many tropical elements such as cycads, palms, and bananas (Manchester, 1994), indicating frost-free conditions; but the early Oligocene Slanting Leaf Beds (33.6 ± 0.19 Ma; Swisher in Best-

[1] This informal name, also used by Bestland and others (1999), applies to the locality formerly referred to as Dugout Gulch by Chaney (1927) and as Iron Mountain assemblage by Meyer and Manchester (1997).

land and Retallack, 1994, p. 137) has mostly temperate deciduous species (Meyer and Manchester, 1997). The Eocene-Oligocene boundary is currently placed at about 34 m.y. (Prothero, 1995); thus the Slanting Leaf Beds assemblage provides a glimpse of the vegetation that became established within about half a million years after the boundary. Was the climatic and floristic change abrupt, occurring over a brief interval of less than one million years, or was it rather gradual?

Detailed investigations of paleosol and alluvial sequences of the Clarno and John Day Formations in Wheeler and Grant Counties, Oregon, with ages approximated on the basis of inferred rates of sedimentation and stratigraphic position in relation to several radiometrically dated horizons, led Bestland and others (1997) to infer stepwise climatic changes across the Eocene-Oligocene transition. They recognized three major paleoclimatic shifts: from tropical to subtropical conditions at 42–43 Ma, subtropical to humid temperate conditions near the end of the Eocene at 34 Ma, and from humid temperate to subhumid temperate conditions at 30 Ma. Bestland and others (1997) note that these shifts seem to be in accord with climatic changes inferred from marine deposits and from paleobotanical studies in the Pacific Northwest. However, our understanding of vegetational and floristic change through the late Eocene remains sketchy and in danger of overgeneralization.

Wolfe (1992, p. 428) called attention to physiognomic differences between vegetation of the John Day Gulch flora of the Clarno Formation (assumed to be about 40 m.y. old but not radiometrically dated) and the Bridge Creek flora of the John Day Formation (radiometrically dated at 33.6–32.6 Ma; McIntosh and others, 1997). Whereas the former fossil assemblage is interpreted as Microphyllous Broad-Leaved Evergreen forest and contains thermophilic plants such as cycads and bananas (genus *Ensete*), the latter represents broad-leaved deciduous forest. The diverse leaf and fruit flora of John Day Gulch has not yet been described, and its age remains speculative. However, if the age estimate of the John Day Gulch assemblage is correct, there remains a gap of about seven million years between these floras; and, as Wolfe acknowledged, it is not certain whether this vegetational change, and the inferred climatic change, occurred gradually over the interval or more abruptly. Nevertheless, Wolfe concluded that there was indeed an abrupt increase of mean annual range of temperature near 33 Ma, based in part on comparison with floras in southwestern Montana. A succession of five floras through 900 m of section of the John Day Formation near Gray Butte, Jefferson County, indicates that the principal interval of climatic cooling may have been ca. 38–39 m.y. earlier, but precise radiometric control is lacking (Smith and others, 1998).

Epoch	Horizon	Unit	Radiometric age
Oligocene	John Day Formation	Slanting Leaf Beds	33.6±0.19 Ma
Eocene		Whitecap Knoll tuff	38.4±0.7 Ma
		Whitecap Knoll shale	
		John Day member A ignimbrite	39.17±0.15 Ma
	Clarno Formation	Hancock Quarry	
		Nut Beds	43.76±0.29 Ma

Figure 3. Chart showing the relative stratigraphic positions and radiometric ages of floras and lithologic units in the vicinity of the Clarno Unit, John Day Fossil Beds National Monument.

The Whitecap Knoll flora, bracketed by radiometric dates indicating an age of about 38.8 ± 0.7 million years, provides a new datum that helps to assess the transition between warm-climate vegetation of the Clarno Formation, and cooler vegetation of the overlying Bridge Creek flora. The purpose of this investigation is to evaluate the diversity, taxonomic affinities, and climatic implications of the Whitecap Knoll flora in comparison with middle Eocene and early Oligocene assemblages of the same region.

GEOLOGIC SETTING

The Whitecap Knoll assemblage takes its name from a white-topped bluff that is somewhat more resistant to erosion than surrounding strata due to an indurated white tuff (Figures 1, 2). The tuff itself has been dated at 38.4 ± 0.7 Ma based on ^{40}Ar/^{39}Ar analyses by C.C. Swisher III (Bestland and Retallack, 1994), providing a minimum age for the underlying fossil assemblage. The fissile, tan, lacustrine shales occur about 4 m below the white tuff, being separated by brownish to tan paleosols (referred to as an Alfisol-like paleosol; Getahun and Retallack, 1991). The shales are among sediments overlying a prominent basaltic andesite, locally mapped as member B, and are situated about 100 m above the basal ignimbrite of the John Day Formation, dated at 39.22 ± 0.03 Ma (Bestland and Retallack, 1994).

The dated white tuff of Whitecap Knoll can be traced at least 3 km east of the knoll along the southern slope of Iron Mountain. Bestland and Retallack (1994) and Bestland and others (1999) referred to this as member F tuff, because it correlates with a white tuff exposed in a cut of Highway 218 about 5 mi to the west-southwest; Robinson and Brem (1981) believed this white tuff to correspond with the member F tuff in its type area to the west near Ashwood. However, the age of the Whitecap Knoll tuff (38.4 ± 0.7

Ma), is significantly older than member F tuff in its type area (32.3 ± 0.12; Smith and others, 1998). The proper correlation of this tuff with respect to the members designated in the Ashwood area remains speculative, although it is certainly well below the distinctive member G tuff, which lies stratigraphically above the Slanting Leaf Beds (Bestland and Retallack, 1994).

METHODOLOGY

The fossil-bearing lacustrine shale of Whitecap Knoll ranges from 1 to 3 m in thickness, and is intermittently exposed over a distance of about 3 km. This treatment is based on specimens excavated from the westernmost exposure of the shale, immediately below Whitecap Knoll. It is located at 44°56.2′N., 120°25.07′W., about 3 km north-northeast of Hancock Field Station on private land adjoining the Clarno Unit of John Day Fossil Beds National Monument. The site is reached in about 30 minutes by a foot path from the field station. Scattered leaf, fruit, and seed remains and occasional fish scales were recovered by splitting the shale with hammers and chisels. We were disappointed to find that freshly removed damp shale quickly disintegrated into small fragments upon exposure as it began to dry, at the same time destroying the fossils. However, this problem was alleviated by wrapping the freshly removed fossil specimens immediately in several layers of toilet tissue, which slowed the drying process sufficiently to prevent cracking. Although the fossils are extremely rare, continued excavation over a few weeks time resulted in a collection sufficient to allow this preliminary evaluation of the flora. Fractured specimens were reassembled with Elmer's glue.

A few specimens from this locality were viewed in the collection of the John Day Fossil Beds National Monument (those cited by Bestland and Retallack, 1994). Additional samples were collected during the summers of 1995–1997 and have been de-

posited in the Paleobotanical Collection of the Florida Museum of Natural History. All specimens cited in the present paper that have catalog numbers prefixed by UF are housed at the Paleobotanical Collection of the Florida Museum of Natural History, University of Florida, Gainesville, Florida. Samples of the shale were also processed for palynology, but no pollen was found to be preserved.

FOSSIL PLANTS

The Whitecap Knoll flora includes three kinds of ferns, three kinds of monocots, and at least 16 species of dicots, including both extinct and extant genera. Among the genera still living today, some are still native in western North America (*Alnus*, *Quercus*, *Mahonia*, *Acer*), while others are native today in eastern North America (*Decodon*), eastern Asia (*Dipteronia*, *Craigia*, *Eucommia*), or both (*Hydrangea*, *Nelumbo*).

The three kinds of ferns (Figure 4A–C) are known only from fragments of the foliage, without fertile parts, and are thus difficult to identify relative to modern fern genera. One of the ferns, with featherlike venation (Figure 4B), appears to match a species present in the White Cliffs locality of the Clarno Formation.

Conifers are notable by their absence in this flora. Pine occurs stratigraphically below, in the Clarno Formation, and above in the Bridge Creek flora, but the distinctive needles and winged seeds are, so far, lacking from the Whitecap Knoll assemblage. The lack of *Sequoia* (common in lacustrine shales of the Clarno Formation) and the absence of *Metasequoia*, which is so common in the overlying Slanting Leaf Beds (and all other Bridge Creek flora localities), is particularly noteworthy. Getahun and Retallack (1991) and Bestland and Retallack (1994) reported *Metasequoia* from Whitecap Knoll, but I reexamined the cited specimen (JODA 3857) and could not agree with the previous identification. The specimen was
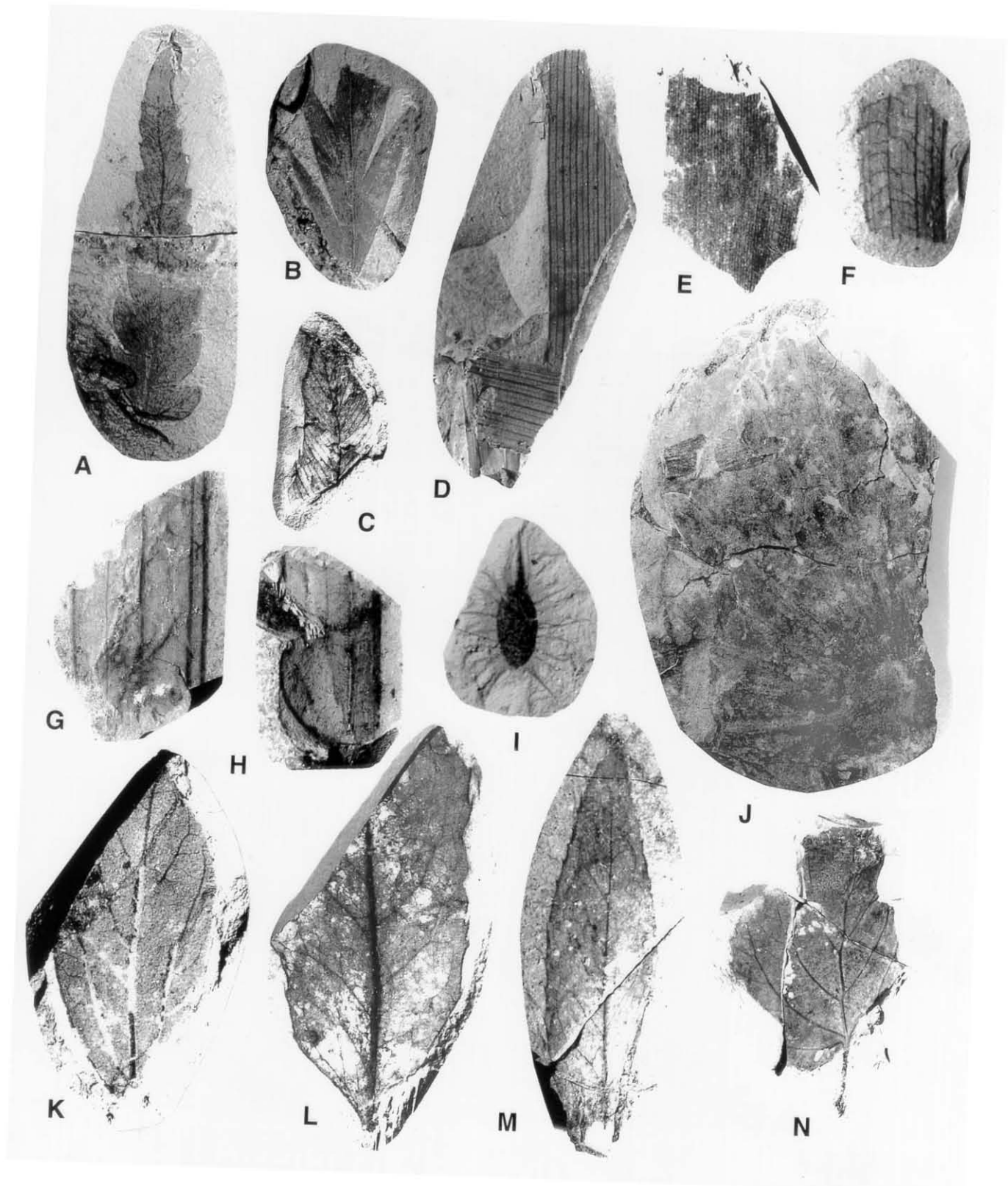
Figure 4. A. Fern 1, UF26285, x1.5. **B.** Fern 2, UF26289, x1.5. **C.** Fern 3, UF26287, x2. **D.** Monocot 1, UF26293, x2.5. **E.** Monocot 2, UF26294, x2.5. **F.** Monocot 3, UF26298, x2.5. **G.** Monocot 3, UF26304, x1.5. **H.** Monocot 3, UF26303, x1.5. **I.** Pondweed, *Ceratophyllum*, spiny fruit, UF26262, x2.5. **J.** Lotus leaf, *Nelumbo*, UF26344., x1. **K.** Lauraceae: *Cinnamomophyllum*, UF26281, x2.5. **L.** *Mahonia*, UF26307, x2. **M.** *Mahonia*, UF26310, x1.5. **N.** Sycamore, *Platanus*, UF26331, x1.

presumed to be a seed cone but does not show any cone scales. In our excavations, we looked especially for conifer foliage but did not observe even a single needle that could represent *Metasequoia*. *Metasequoia* was present already in the middle Eocene of Washington and British Columbia (Basinger, 1981; Wehr and Schorn, 1992). Its arrival in central Oregon evidently was sometime after 38 Ma but prior to 33 Ma.

Monocots are locally common in the assemblage, represented mostly by fragmentary remains. There are three kinds, distinguishable by their venation patterns. The first (Figure 4D) has three main orders of parallel veins organized in such a way that veins of intermediate thickness alternate with the thickest veins, with much finer parallel veins lying between them. Short, thin, wavy cross veins connect between the thickest veins and the adjacent medium-thick veins. The second kind (Figure 4E) has parallel veins that are all about equal in strength and closely spaced cross veins. The third kind (Figure 4F–H) has widely spaced thick veins interspersed with one to three veins of intermediate thickness, and with five to ten very fine veins occurring between the adjacent thick and medium-thick veins. In this species, the cross veins are more widely spaced than in the second kind. They are wavy and traverse between adjacent medium or thick veins, uninterrupted by the finer veins. Although the precise affinities of these plants are uncertain, their venation does not correspond to *Sabalites*, the palm leaves found in older floras of the region (Hancock Canyon and Nut Beds).

Ceratophyllaceae. The pondweed, *Ceratophyllum*, a rootless plant that grows submerged below the water surface, is represented in the fossil flora by its distinctive elliptical spiny fruit (Figure 4I). Although not previously known from the Tertiary of Oregon, the fruits of this genus are recorded from the middle Eocene of Washington (Wehr, 1995) as well as the Paleocene of Montana, Eocene of Wyoming, and Miocene of Nevada (Herendeen and others, 1990).

Nelumbonaceae. *Nelumbo*, the lotus, is confirmed by fragments of the large peltate floating leaves, with primary veins radiating in all directions from the center of the lamina (Figure 4J). A fine honeycomb pattern of thin veins visible under the dissecting microscope verifies that this is *Nelumbo* rather than one of the other genera of waterlilies. This represents the first report of lotus fossils from Oregon. Although widespread in the fossil record (e.g., Hickey, 1977), *Nelumbo* is more restricted in its modern distribution, with one species in eastern North America, extending south to Colombia, and a second species extending from warm parts of Asia to Australia.

Lauraceae. The Avocado family is represented by some entire-margined leaves corresponding to *Cinnamomophyllum* (a fossil genus for leaves similar to those of Cinnamon) in having a strong pair of basal secondary veins that depart from the midvein well above the base of the lamina and ascend more than $2/3$ the length of the lamina before looping at the margin (Figure 4K). There is also a vein that runs directly along the margin. Such leaves occur in more than one living genus of the Lauraceae, so the precise identity with modern genera remains uncertain. Another leaf that might represent the Lauraceae is slender, with entire margins and more standard pinnate secondary venation (Figure 7A) and is provisionally placed in *Litseaphyllum*.

Berberidaceae (*Mahonia*). The Oregon grape genus is represented by a few leaflets in the assemblage (Figures 4L,M). Each leaflet has a serrate margin with a thick marginal vein and spiny teeth. The secondary veins are pinnate and camptodromous, giving rise near the margin to tertiary veins that either loop or enter the teeth. The same genus is present in the Slanting Leaf Beds and other assemblages of the Bridge Creek flora, but that species, *M. simplex*, is distinguished by fewer secondary veins and fewer but more prominent teeth.

Platanaceae. The sycamore family is represented by many fragmentary leaf specimens with regularly spaced blunt teeth (e.g., Figures 4N, 5E,H,I) and by a few isolated fruitlets (Figure 5C). As is the case with most extant species of *Platanus*, the base of the petiole is much enlarged (Figure 5D). There is no trace of *Macginitiea*, the common extinct sycamore (plane tree) of the Clarno Formation (also known from the Sumner Spring flora of the John Day Formation near Gray Butte; Manchester, 1986; McFadden, 1986).

Ulmaceae. Elm was also a component of the flora, as indicated by a few fragmentary specimens of *Ulmus* leaves (e.g., Figure 6F) showing the characteristic thick petiole, basally asymmetrical lamina, and serrate margin. In addition, two of the distinctive winged fruits have been recovered (e.g., Figure 6K). *Ulmus* is present both in the Clarno and Bridge Creek floras, but is more diverse in the later.

Fagaceae (*Quercus*, 2 species). The oaks are represented by two kinds of leaves in the assemblage. Both have narrow elliptical laminae with many (15–20) pairs of secondary veins. One kind (Figure 5A) has mostly entire-margined leaves but with a few inconspicuous teeth where secondary veins enter the margin, particularly in the upper half of the leaf. The other type (Figures 5B,G) has regularly spaced prominent, often spiny teeth corresponding to each of the secondary veins. This second kind is similar in general form to *Castanea* as well as *Quercus*, but the former is ruled out by the presence of a marginal vein in the fossil laminae—a feature of oaks but not chestnuts.

Betulaceae. The genus *Alnus* (alder) is represented by a few frag-

mentary leaves (Figures 5F, 6A). They are similar in form and venation to *Alnus heterodonta* of the Bridge Creek and West Branch Creek floras but tend to have more subtle teeth. As yet, the distinctive fruits and fruiting cones have not been recovered, although they are common in the Clarno and Bridge Creek floras.

Juglandaceae. The walnut family is represented by at least one kind of leaflet (Figures 6B,C) and two genera of wind-dispersed winged nuts in the Whitecap Knoll assemblage. *Palaeocarya* is the name given to fossil winged nuts that resemble the fruits of two modern genera in the Juglandaceae: *Engelhardia* (of modern Asian distribution), and *Oreomunnea* (of modern tropical American distribution). The fruits of *Palaeocarya* from Whitecap Knoll (Figures 6L,M) are similar—in form
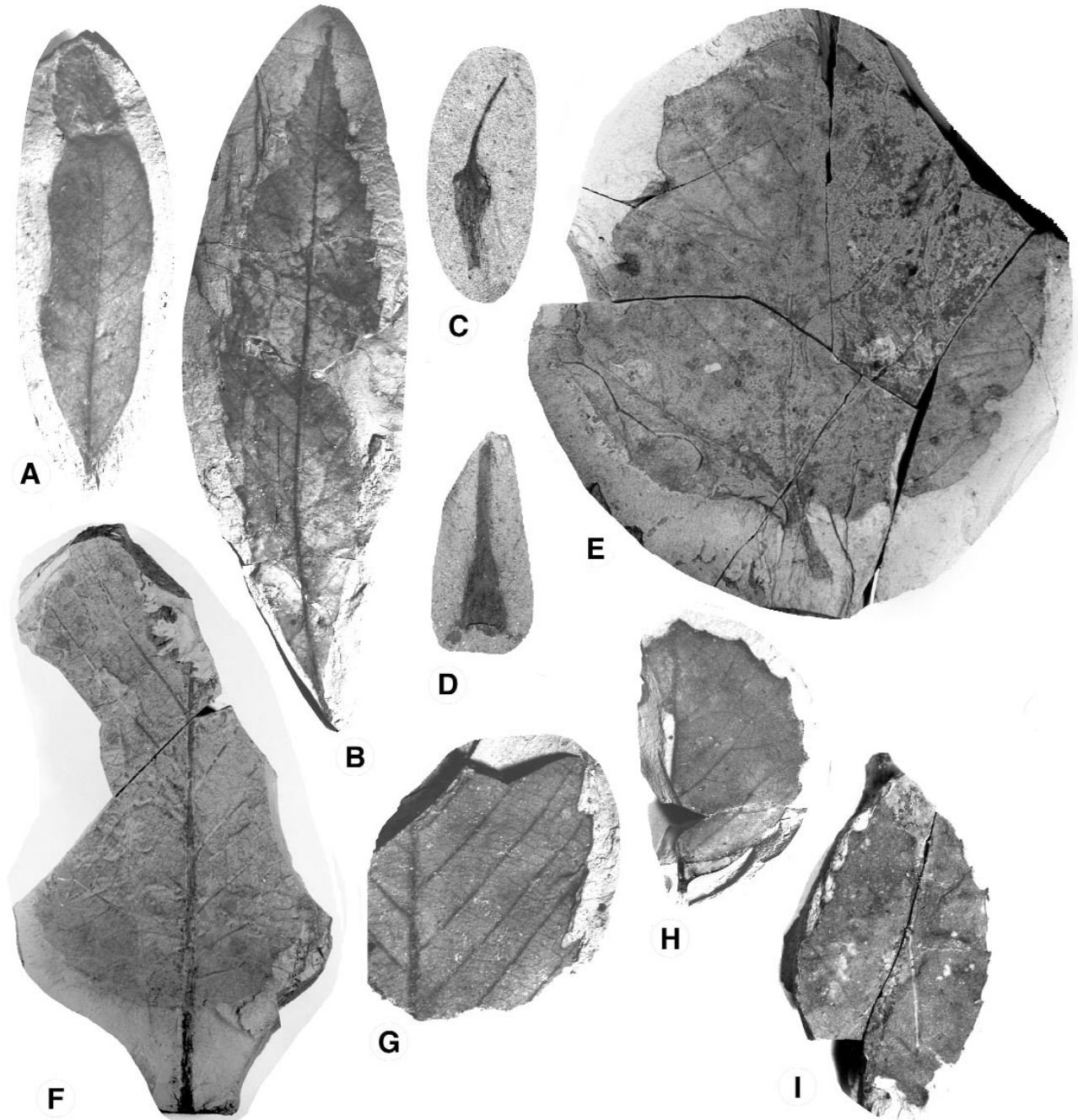
Figure 5. A. Oak leaf, *Quercus*, with a few small teeth on the margin, UF26354, x1.5. B. *Quercus* with more prominent teeth, UF26072, x1. C. Sycamore fruitlet, *Platanus*, UF26386, x3. D. Characteristic expanded petiole base of *Platanus*, UF30544 x1. E. *Platanus* leaf, UF30896, x1. F. Alder, *Alnus*, UF26339, X1. G. *Quercus* with detail of venation, UF26371, x2. H. *Platanus*, UF26077, x1. I. *Platanus*, UF26329, x1.5.
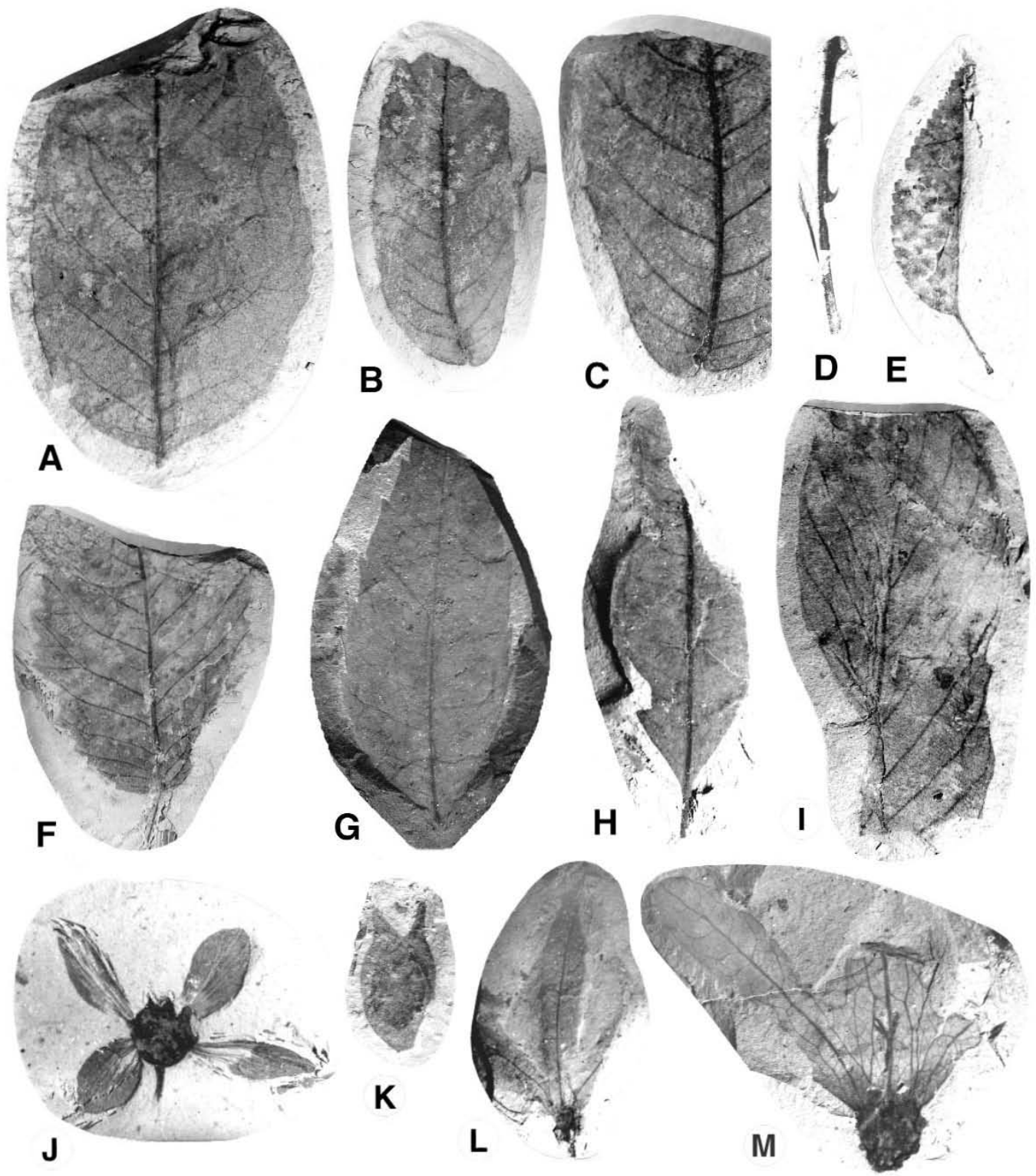
Figure 6. A. *Alnus*, UF26347, x2. B. Juglandaceae, UF26073, x1 C. Counterpart of the leaflet in B, UF26073′, x2. D. Rose family prickly twig, UF26277, x1. E. Rose leaflet, *Rosa* sp., UF26273, x2. F. Elm leaf, *Ulmus* sp., UF26264., x1. G. Unidentified leaflet, UF30895, x1.25. H. *Decodon*, UF26284, x2. I. Rhamnaceae, showing very closely spaced tertiary veins, UF26369, x3. J. 4-winged fruit of *Cruciptera*, UF26231, x2.5. K. Winged fruit of Elm, *Ulmus*, UF 26313, x4. L. *Palaeocarya*, UF26074, x1.1. M. *Palaeocarya*, UF26248, x2.
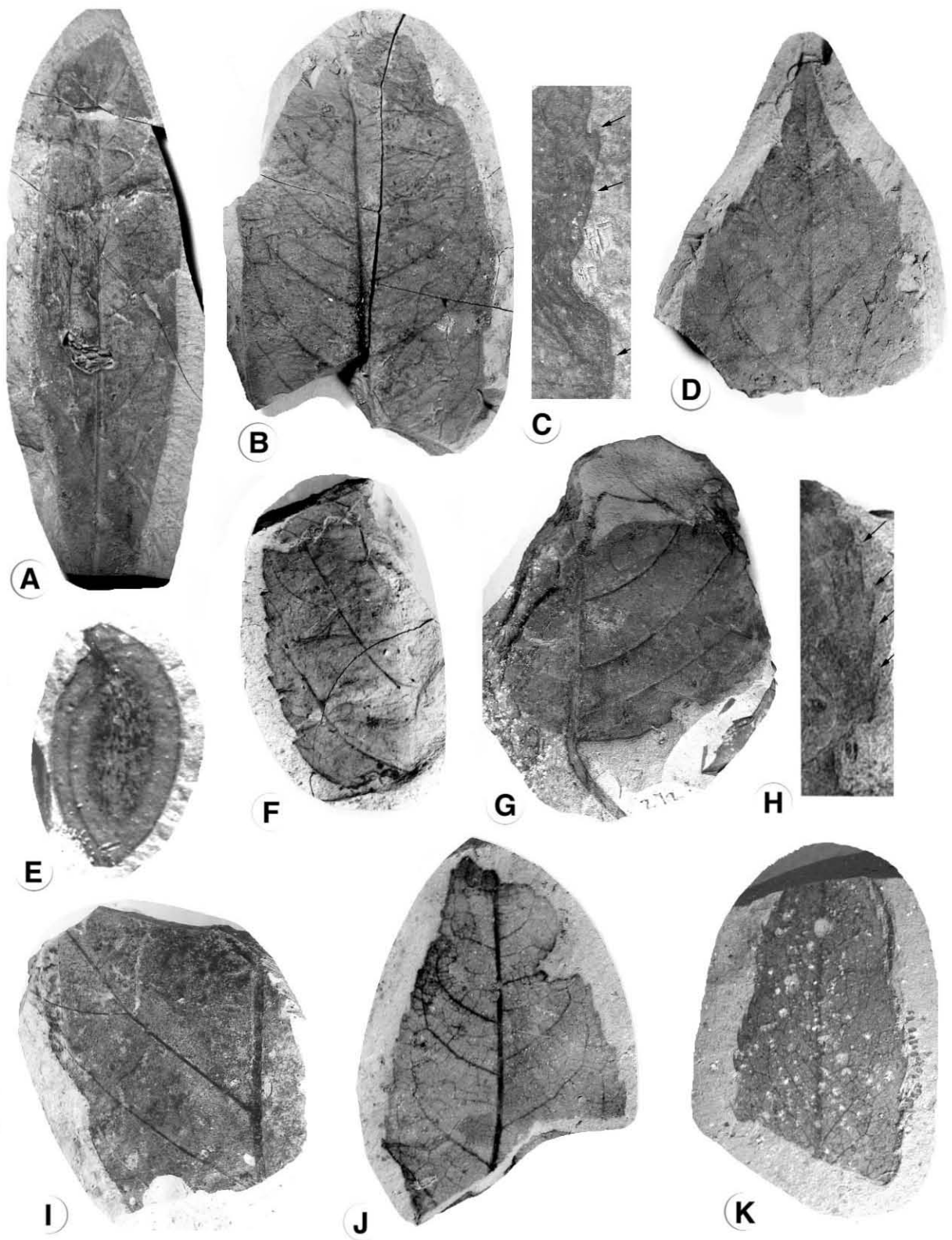
Figure 7. A. *Litseaphyllum*, UF 30540, x1. B. Unidentified leaf with prominent intersecondary veins and fine marginal serration, UF26346, x1. C. Detail of margin from B, showing teeth (arrows), x3. D. Apical portion of an unidentified serrate leaf, possibly *Acer*, UF 26352, x1.5. E. Elliptical winged fruit of *Eucommia montana*, UF , UF26321 x4. F. Unidentified serrate leaf, UF26345, x2. G. Basal portion of a leaf with prominent petiole, UF 26327, x1. H. Detail of margin from G, showing teeth (arrows), x. 2.5. I. Unidentified leaf with crenulate margin, UF26340, x1.25. J. Unidentified serrate leaves, UF26342, x 2.5. K. Small serrate leaf, UF26306, x 3.
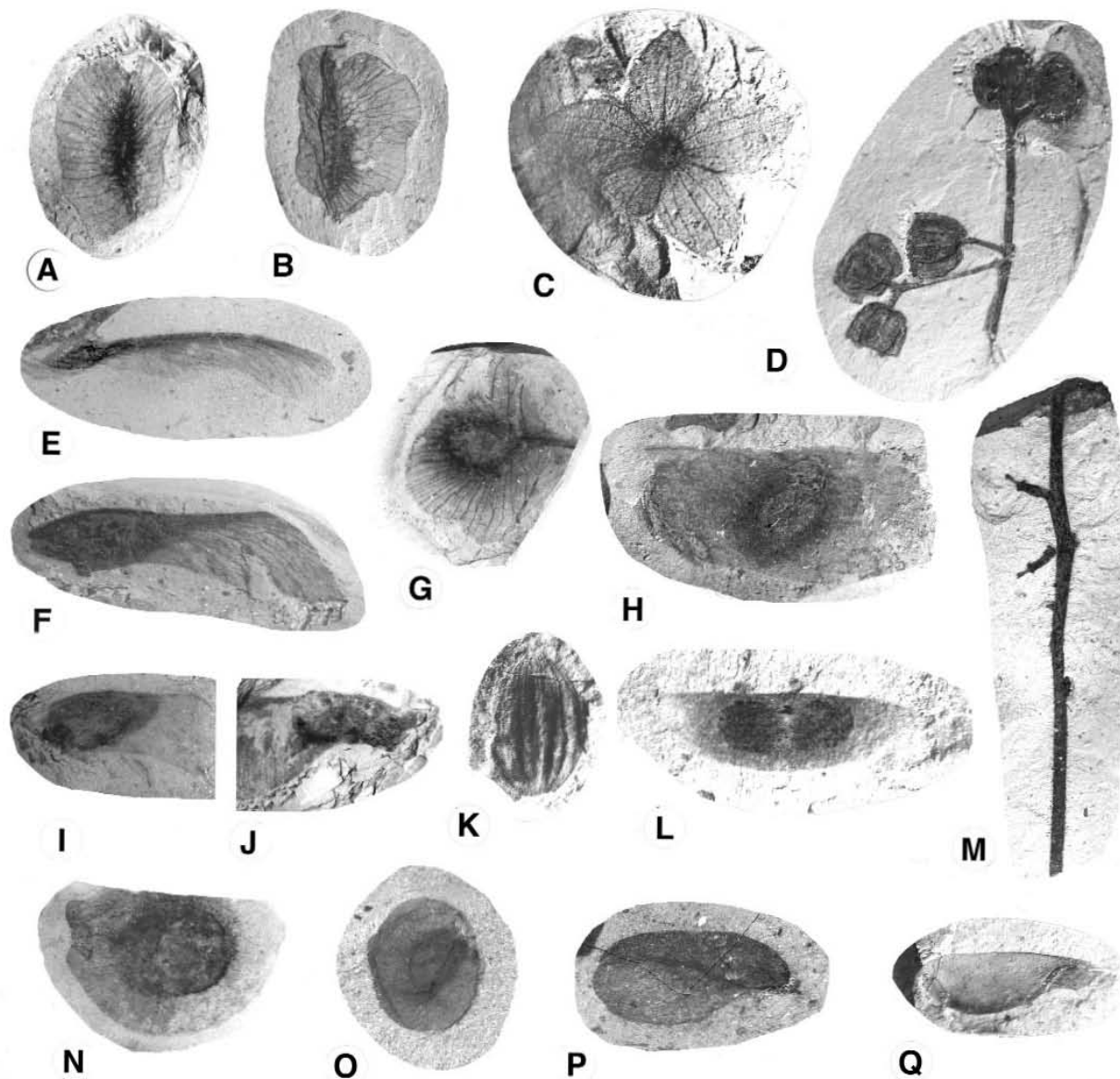
Figure 8. A. Winged fruit valve of *Craigia*, UF26261, x2. **B.** *Craigia*, UF26259, x2. **C.** *Florissantia ashwilli*, UF26271, x1.5. **D.** *Hydrangea infructescence*, UF26376, x2.5. **E.** *Acer* 1, UF26242, x2.5. **F.** *Acer* 2, 30533, X2.5. **G.** *Dipteronia* winged fruit, UF26428, x2. **H.** *Ailanthus*, UF26255, x2. **I.** *Acer*, UF26241, x2. **J.** *Acer*, UF26240, x2. **K.** *Nyssa*, UF26383, x1.5. **L.** *Catalpa*, UF26394, x6. **M.** Unidentified fruiting axis with fruits previously shed, 26392, x 1.5. **N.** Unidentified winged seed with prominent attachment scar, UF26244, x2. **O.** *Beckerospermum ovalicarpa* seed, UF26391, x3.5. **P.** Unidenfied winged seed, UF30546, x4. **Q.** Unidentified winged seed, UF26377, x2.

and venation of the trilobed wing and in presence of a long style—to those known from the West Branch Creek and Cherry Creek lacustrine shale localities of the Clarno Formation.

Cruciptera is an extinct genus of the walnut family with a nut surrounded by four orthogonally arranged, straplike wings (Figure 6J).

Getahun and Retallack (1991) referred to these winged fruits as *Tetrapteris*, a modern genus of the Malphigiaceae, but subsequent study showed that they belong to the fossil genus *Cruciptera* of the Juglandaceae. *Cruciptera simsonii* is a characteristic species of the Clarno Formation, occurring at the Nut Beds and in lacustrine deposits of West

Branch Creek and Cherry Creek (Manchester, 1991). Whereas the *C. simsonii* specimens have a wing span of 21–41.5 mm, the *Cruciptera* fruits at Whitecap Knoll range only from 12 to17 mm, placing it in the size range of *Cruciptera schaarschmidtii*, a species first described from the middle Eocene of Germany (Manchester and others, 1994). Similarly

small fruits with wingspans of 12–19.5 mm (n=16) also occur in the Sumner Spring assemblage.

Eucommiaceae. Distinctive elliptical winged fruits of *Eucommia*, a genus native only to China today, are especially abundant in the deposit (Figure 7E). In their review of the North American fossil record of this genus, Call and Dilcher (1997, Figures 29,30) illustrated two Whitecap Knoll specimens which they assigned to the *Eucommia montana*—a species known also from lacustrine shales of the Clarno Formation and from localities in Montana, Utah, and Colorado. Although present in the middle Eocene shales of the Clarno Formation, this genus has never been observed in the Bridge Creek flora.

Malvaceae. *Craigia* is a genus of the Malvaceae (as broadly circumscribed including Tiliaceae) that grows today in southern China and Vietnam. The genus has an excellent fossil record, based on its distinctive winged fruit valves (Figures 8A,B), from the Tertiary of Europe and Asia as well as western North America. In North America, *Craigia* is common in the Bridge Creek flora (Meyer and Manchester, 1997; called *Pteleaecarpum* by Manchester and Meyer, 1987). The genus is not known from middle Eocene deposits of the Clarno Formation, (not found in the Nut Beds, West Branch Creek, or Cherry Creek) but does occur in the presumed late Eocene John Day Gulch flora.

Flowers of the extinct genus *Florissantia* are known from Eocene and Oligocene localities in western North America (Manchester, 1992) and the Miocene of Sikhote Alin (Manchester, 1999). The small size of the Whitecap Knoll calyces and prominence of sepal lobes (Figure 8C) identifies the species as *Florissantia ashwilli*, which also occurs in the Sumner Spring flora at Gray Butte. Although formerly placed in the Sterculiaceae, that family has recently been merged with Tiliaceae and Bombacaceae in the more broadly circumscribed Malvaceae.

Hydrangeaceae. *Hydrangea* is represented by a single fruiting branch (Figure 8D). The woody fruit capsules show a flat apical disk and remnants of at least two styles and have prominent longitudinal ribs, conforming to the fruits of other modern and fossil species. The attractive four-parted calyces, known both in the Clarno Formation (Manchester, 1994, pl. 58, fig. 6) and in the Bridge Creek flora (Meyer and Manchester, 1997, pl. 45, figs. 7,8), have not yet been recovered from the Whitecap Knoll assemblage.

Rosaceae. The rose genus, *Rosa*, can be recognized on the basis of its small leaflets with closely spaced, rounded teeth (Figure 6E). Stems with rosaceous prickles have also been recovered (Figure 6D). *Rosa* is not known from the Clarno Formation but occurs in the Slanting Leaf Beds and other localities of the Bridge Creek flora (Meyer and Manchester, 1997).

Nyssaceae. The impression of an ellipsoidal woody fruit with longitudinal ribs (Figure 8K) is similar to that which might be made by the stone of *Nyssa*, the tupelo tree. However, this identification remains uncertain because the impression of germination valves could not be seen. *Nyssa* is represented in the Nut Beds flora of the Clarno Formation but has not been confirmed in the Bridge Creek flora. Some of the modern species grow along lakes and streams and in swampy areas.

Sapindaceae. The maple family, traditionally called the Aceraceae but now merged with the Sapindaceae (Judd and others, 1999), is represented in the Whitecap Knoll flora by two extant genera: *Acer* and *Dipteronia*. Four fragmentary *Acer* fruits have been recovered from the Whitecap Knoll assemblage (Figures 8E,F,I,J). No complete leaves have been recovered, but one fragmentary specimen (Figure 7D) appears to represent one of the lobes of a maple leaf. *Acer* is not found in the middle Eocene lacustrine assemblages of the Clarno Formation but occurs in the

late Eocene John Day Gulch and at the Sumner Spring assemblages.

Native to China today, *Dipteronia* has distinctive fruits that are readily recognized as fossils (Figure 8G; Manchester, 1999). The fruits are also known as rare components of Clarno lacustrine localities. A single specimen has been identified in the Bridge Creek flora (Meyer and Manchester, 1997, pl. 60, fig. 18). They are sometimes encountered in the Sumner Spring flora near Gray Butte (McFadden, 1986).

Rhamnaceae. A small leaf with entire to slightly undulating margins, pinnate secondary veins, and thin, very closely spaced, parallel tertiary veins (Figure 6I) compares favorably with leaves of extant *Berchemia* and *Rhamnidium* of the Rhamnaceae.

Simaroubaceae. The Chinese tree of heaven, *Ailanthus*, is known from a single specimen of its characteristic biwinged fruit (Figure 8H). *Ailanthus* occurs in lacustrine floras of the Clarno Formation and in the Sumner Spring flora at Gray Butte but has never been observed in the Bridge Creek flora.

Lythraceae. A small slender leaf with an intramarginal vein and irregular tertiary venation (Figure 6H) corresponds to those identified as *Decodon* from the the Bridge Creek flora (Meyer and Manchester, 1997). The leaves correspond in venation to the single living species, *D. verticillata* of eastern North America, but the lamina is relatively small, as are those from the Sumner Spring and Bridge Creek floras. The genus is known from silicified fruits in the Clarno Nut Beds flora (Manchester, 1994).

Bignoniaceae. *Catalpa* is recognized by a single seed (Figure 8L), which is bilaterally symmetrical with a straight, straplike wing on either side of the central body and with a tuft of hairs at the distal margin of each wing. *Catalpa* seeds are also present at two assemblages of the Bridge Creek flora (Meyer and Manchester, 1997).

Beckerospermum. This is a winged seed of uncertain affinity (Figure 8O) that is relatively common at the Slanting Leaf Beds and most other localities of the Bridge Creek flora (Meyer and Manchester, 1997) and is also known from the Mormon Creek flora of Montana (Becker, 1960, pl. 30, figs. 16-20) and Haynes Creek flora of Idaho (Axelrod, 1998, pl. 9, fig. 6).

Unidentified reproductive structures. A few of the fruits and seeds from Whitecap Knoll remain mysterious. Included are a fruiting axis from which the fruits had shed prior to fossilization (Figure 8M), an oval winged seed (Figure 8N), and some laterally winged seeds (Figures 8P,Q). Although superficially similar to seeds of *Cedrela* and pinaceous conifers, the cellular patterns of the wings do not correspond (Howard Schorn, written communication, March 2000).

Unidentified leaves. Current collections include several leaf types whose identity remains uncertain. I illustrated them here in the hope that future work will be able to link them to fossils from other sites and/or to extant genera. They include a serrate leaflet with the secondary veins terminating in prominent acute teeth (Figure 6G), a leaf with common intersecondary veins and very finely serrate margin (Figures 7B,C), one with a crenulate margin (Figure 7I), and three additional serrate leaf types (Figures 7F,J,K).

VEGETATION TYPE

The Whitecap Knoll plant assemblage includes elements representing both the aquatic plant community of the lake and the surrounding forest community. The aquatic indicators are *Ceratophyllum*, which grows suspended in the water without roots, and *Nelumbo*, which has floating leaves with long petioles that attach a rhizome located at the bottom of the pond or lake. Together, these plants indicate quiet water conditions and relatively shallow water depth. *Decodon* is also at home in

shallow water areas. It is likely that some of the unidentified monocot foliage represents marshy plants like *Typha* (cattail).

Aside from the aquatic plants and the three kinds of ferns, the remaining plants represent woody trees and shrubs. Some were broad-leaved evergreens, including Oregon grape (*Mahonia*) and perhaps *Cinnamomophyllum*, but most appear to have been deciduous (e.g., *Platanus*, *Quercus*, *Ulmus*, *Acer*, *Dipteronia*, *Rosa*, *Catalpa*). These plants are typical of temperate forest today.

COMPARISON WITH OLDER AND YOUNGER FLORAS IN THE REGION

The Whitecap Knoll flora has a moderate diversity of about 35 species, but this is lower than the Nut Beds (173 species), West Branch Creek (55 species), and the Slanting Leaf Beds (44 species). It lacks remains of palms, cycads, bananas, Menispermaceae and other thermophilic indicators common in the Clarno Formation Nut Beds, West Branch Creek, Gosner Road, and John Day Gulch localities. Table 1 compares the taxonomic composition of the Whitecap Knoll flora with specified Clarno and John Day Formation floras. Elements shared with the Clarno flora but not known from the Bridge Creek flora include *Ailanthus*, and *Eucommia*. Two genera are shared with the Bridge Creek flora that are not known from the Clarno: *Rosa* and *Catalpa*.

At the species level, the Whitecap Knoll flora shows greater similarity to the Sumner Spring flora near Gray Butte than to the Clarno or Bridge Creek floras. In the cases of *Florissantia*, and *Cruciptera*, the Whitecap Knoll species is distinct both from those in the middle Eocene localities of the Clarno Formation (West Branch Creek, White Cliffs, Gosner Road), and from those in the Oligocene Bridge Creek flora but corresponds to those known from the late Eocene Sumner Spring flora. The Sumner Spring flora is situated

stratigraphically below John Day Formation member B basalts, in lacustrine sediments interpreted to represent John Day member A (Smith and others, 1998). In contrast, the Whitecap Knoll flora occurs above basalts that were mapped as member B (Bestland and others, 1999). Whether the member B basalts are actually coeval in these different areas, is uncertain. Whole-rock radiometric dates of this basalt show a lack of precision due to alteration (Smith and others, 1998). If the B basalts are assumed to be coeval, then the Sumner Spring flora predates the Whitecap Knoll flora. However, the maximum age of the Sumner Spring flora is constrained by the radiometric dates of 39.22 ± 0.03 Ma on the basal ignimbrite of the Formation. If the Whitecap Knoll flora is correctly placed at about 38.8 Ma, then the Sumner Spring flora would be less than a million years older.

The Whitecap Knoll flora is about five million years older than the overlying Slanting Leaf Beds assemblage and differs in various respects, due to the disappearance of some taxa and the appearance of new ones, perhaps partially in response to changing climate. The apparent absence of conifers is striking, compared to the Clarno localities which have *Pinus*, *Sequoia*, and Taxaceae. *Metasequoia*, which was to become a dominant in the Slanting Leaf Beds and other assemblages of the Bridge Creek flora, is not seen in the Whitecap Knoll flora, although it was already present in the middle Eocene of Washington. Its arrival in the John Day basin evidently occurred sometime between 38 and 33.8 Ma.

CLIMATE

The floristic composition suggests temperate climate. Exclusively tropical to subtropical plants such as cycads, palms, bananas, and various families of lianas, seem to be absent, suggesting winters with frost. With the exception of Oregon grape, which is known to tolerate freezing temperatures, broad-leaved ever-

Table 1. List of the plant genera in the Whitecap Knoll assemblage, showing shared (×) occurrences in other selected Eocene and Oligocene assemblages of north-central Oregon: NB = Nut Beds, WBC= West Branch Creek, JDG = John Day Gulch, WCK = Whitecap Knoll, SS= Sumner Spring, SLB= Slanting Leaf Beds, FO = Fossil-Wheeler High School

Taxa	Clarno Formation			John Day Formation			
	NB	WBC	JDG	WCK	SS	SLB	FO
Fern 1 (Figure 4A)				×			
Fern 2 (Figure 4B)		×		×			
Fern 3 (Figure 4C)				×			
Monocot 1 (Figure 4D)				×			
Monocot 2 (Figure 4E)				×			
Monocot 3 (Figure 4F-H)				×			
Ceratophyllum (Figure 4I)				×			
Nelumbo (Figure 4J)				×			
Cinnamomophyllum (Figure 4K)	×	×	×	×	×	×	
Mahonia (Figure 4L,M)		×	×	×	×	×	×
Platanus (Figure 4N, 5E,H,I)	×	×	×	×	×	×	×
Quercus sp. 1 (Figure 5A)				×	×		
Quercus sp. 2 (Figure 5B,G)				×		×	×
Alnus (Figure 5F, 6A)		×	×	×	×	×	×
Palaeocarya (Figure 6L,M)	×	×	×	×	×	×	×
Cruciptera (Figure 6J)	×	×	×	×	×	×	×
Eucommia (Figure 7E)		×	×	×	×		
Ulmus (Figure 6F,K)		×	×	×	×	×	×
Hydrangea (Figure 8D)	×	×		×		×	×
Rosa (Figure 6D,E)				×	×	×	×
Rhamnaceae (Figure 6I)	×	×	×	×			
Acer (Figure 8E,F,I,J)			×	×	×	×	×
Dipteronia (Figure 8G)		×		×	×		
Ailanthus (Figure 8H)		×	×	×	×		
Florissantia (Figure 8C)		×	×	×	×	×	×
Craigia (Figure 8A,B)			×	×		×	×
Decodon (Figure 6H)	×	×	×	×	×	×	×
Beckerospermum (Figure 8O)				×	×	×	×
Catalpa (Figure 8L)				×			×

green plants are also rare: the flora is dominated by deciduous elements. The absence of large-leaved broad-leaved evergreens is another indication that the climate was not as warm as during deposition of the Clarno Formation. This suggests that the transition to temperate climate had already occurred by about 38.8 Ma.

Using the simple linear correlation reported by Wolfe (1979; also Wing and Greenwood, 1993) between the percentage of dicotyledonous species with entire-margined (not serrated or lobed) leaves and mean annual temperature derived from modern vegetation, it is possible to infer the approximate mean annual temperature (MAT) of fossil leaf assemblages. For this exercise, I used the equation derived from Wolfe's work on modern vegetation of China (Wolfe, 1979): MAT (°C) = $1.14 + 0.306 \times E$, where E is the percentage of entire-margined leaves. The dicotyledonous leaves from Whitecap Knoll include five species that are entire margined and 14 that are not (toothed or spiny along the margin). Hence, about 26 percent are entire margined, in comparison with 23 percent in Iron Mountain (Slanting Leaf Beds). Table 2 compares the results of this univariate evaluation of MAT for selected floras of the Clarno and John Day Formations.

The Whitecap Knoll flora indicates a MAT only about 1° higher than that of the Slanting Leaf Beds (considering the margin for error, they can be considered as overlapping) but perhaps 8° lower than that of the Nut Beds, and 5° lower than White Cliffs. The Oligocene assemblage of Fossil, Oregon (ca. 32.6 Ma, McIntosh and others, 1997; Meyer and Manchester, 1997), actually appears a few degrees warmer than the Whitecap Knoll flora (Table 2). Based on the relatively low values of MAT computed for both the Sumner Spring and the Whitecap Knoll flora, we may infer that the regional cooling had already occurred or was in progress by 38.8 Ma, well before the Eocene-Oligocene boundary (34 m.y.).

Our current understanding of the Whitecap Knoll flora remains limited by the relatively small number of samples, filling only three drawers in our museum cabinets (vs. 30 drawers from West Branch Creek, 25 from the Iron Mountain assemblage). It may be that continued collecting will bring forth significant additional taxa helpful to a more reliable reconstruction of the flora and climate.

ACKNOWLEDGMENTS

Table 2. Comparison of conifer abundance, diversity of dicotyledons, proportion of entire-margined leaves and inferred Mean Annual Temperature (MAT) for selected floras of the Clarno and John Day Formations, north-central Oregon

	Clarno Formation				John Day Formation			
	West Branch Creek	Nut Beds	White Cliffs	John Day Gulch	Sumner Spring	Whitecap Knoll	Slanting Leaf Beds	Fossil
Age (to nearest 0.5 Ma)	45	44	44.5	40	38	39	33	32.5
No. conifers	3	3	3	5	1	0	2	2
No. dicot species	41	69	61	40	19	19	31	53
No. entire margined	17	33	26	12	4	5	7	19
Percent entire margined	42	52	43	30	21	26	23	35
Inferred MAT (°C)	14	17	14	10.3	7.6	9	8–9	11–12

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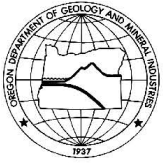
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Places to see—Recommended by the Oregon Department of Geology and Mineral Industries:

Sheep Rock, one of the landmarks in the John Day Fossil Beds National Monument, Grant County (National Park Service photo, negative no. 370).

Below a cap of erosion-resistant basalt, eroded channels lead down throught 1,000 ft of ancient volcanic ash to the John Day River. This ash, now turned to claystone, contains the fossils of plants and animals from 25 million years ago. Sheep Rock is located 2 mi north of the junction of U.S. Highway 26 and Oregon Highway 19, west of Dayville, close to the John Day Fossil Beds National Monument headquarters at the Cant Ranch on Highway 19.

IN THIS ISSUE:

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and
Geology and Mineralization of the Blue River mining district**