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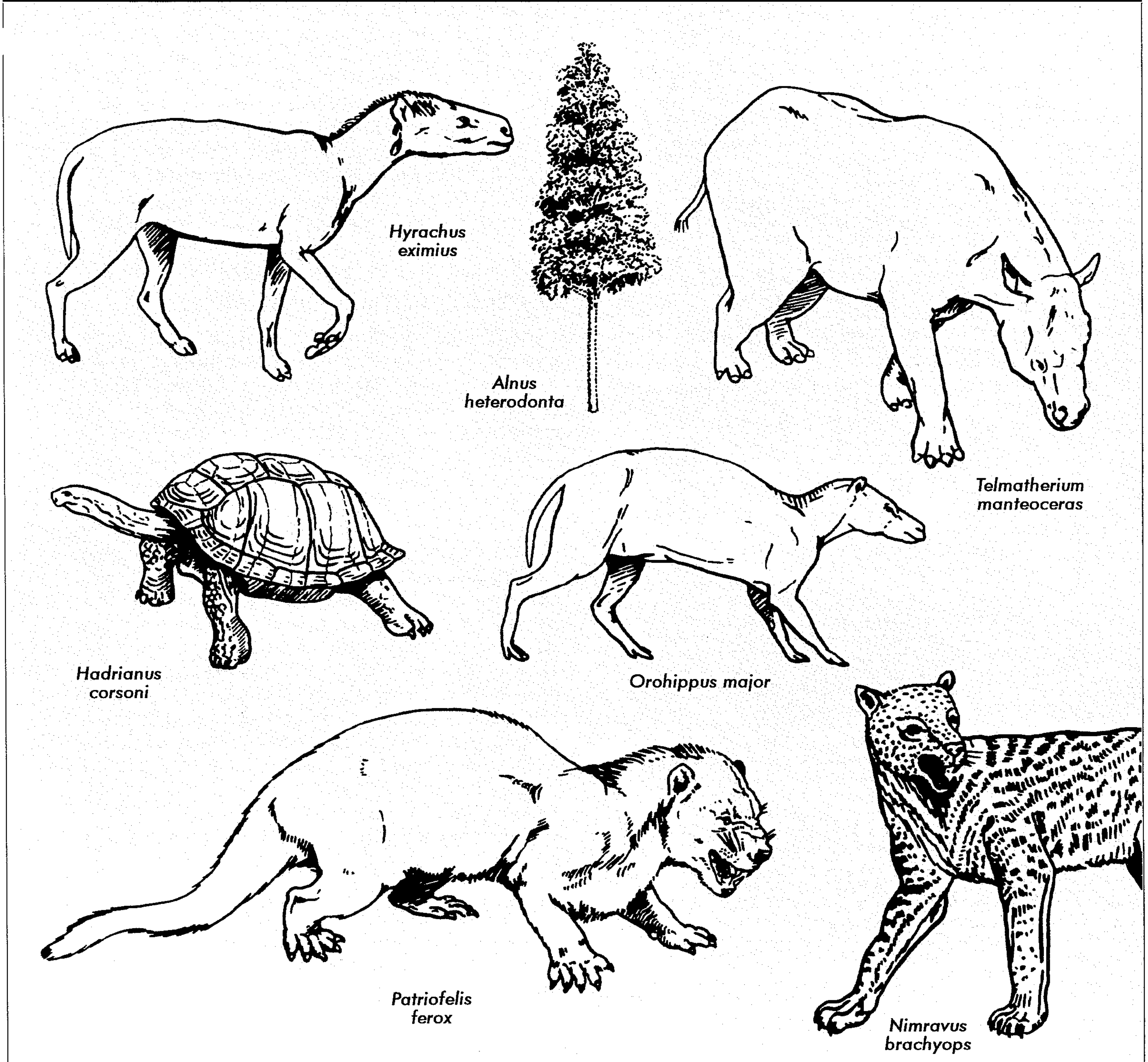

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Reconstructions of Eocene and Oligocene Plants and Animals of Central Oregon

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Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted. If manuscript was prepared on common word-processing equipment, a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, high-density diskette only). Graphics should be camera ready; photographs should be black-and-white glossies. All figures should be clearly marked; figure captions should be together at the end of the text.

Style is generally that of U.S. Geological Survey publications. (See USGS *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office (address above).

Cover illustration

Collage of samples from reconstructions of plants and animals from fossils of the John Day Fossil Beds National Monument. Illustrations and discussion of such reconstructions are contained in the article beginning on next page.

In memoriam: Volunteer Shirley O'Dell

Shirley O'Dell, volunteer at the Nature of the Northwest Information Center, died March 30, 1996.

Born in Minneapolis, Minnesota, she spent most of her life in Portland, Oregon. She was a secretary at Charles F. Berg, at an investment company, and at Columbia Grain Company. After her retirement, she worked as a volunteer at St. Vincent's Medical Center Gift Shop and at the Nature of the Northwest Infomation Center. She was a member of the Geological Society of the Oregon Country (GSOC) for more than 30 years and held various elective and appointive offices, including secretary and auditor.

Shirley was an avid worldwide traveler. She is missed at the Center because she contributed so much as a volunteer—her knowledge about Oregon, interest in geology, and willingness to do careful, meticulous work.

She is survived by one brother and many friends. □

DOGAMI will map tsunami hazard zones at Newport and Seaside-Gearhart

The Oregon Department of Geology and Mineral Industries (DOGAMI) has received support to produce tsunami hazard maps for the Yaquina Bay area of Newport and for the cities of Seaside and Gearhart. The Seaside-Gearhart project is funded by a grant of $132,000 from the Petroleum Antitrust Grant Program administered by the Oregon Department of Justice. The Newport project is funded by a grant of $85,000 from the National Earthquake Hazard Reduction Program of the U.S. Geological Survey.

Both projects will produce maps of expected tsunami flooding from undersea earthquakes on the nearby Cascadia subduction zone fault system. Great (magnitude 8–9) earthquakes on this fault system have caused large tsunamis to strike the Oregon coast every 300 to 500 years, the last one being 300 years ago. Such tsunamis strike the coast within 30 minutes or less after the earthquake, so evacuation guided by accurate knowledge of possible flooding zones is essential.

DOGAMI is working in collaboration with the Oregon Graduate Institute of Science and Technology and the Geology Department of Portland State University to generate the necessary data for these maps. For information about the projects, contact George Priest at the Portland office of DOGAMI, phone 503-731-4100. □

DOGAMI now has Internet home pages

The Oregon Department of Geology and Mineral Industries (DOGAMI) can now be found on the Internet with its own home pages:

The general Department address
http://sarvis.dogami.state.or.us
The Nature of the Northwest Information Center:
http://www.naturenw.org
The Mined Land Reclamation Program:
http://www.proaxis.com/~dogami/mlrweb.shtml □

Reconstructions of Eocene and Oligocene plants and animals of central Oregon

by Gregory J. Retallack, Erick A. Bestland, Department of Geological Sciences, University of Oregon, Eugene, OR 97403-1272, and Theodore J. Fremd, John Day Fossil Beds National Monument, HC 82 Box 126, Kimberly, OR 97848-9701

ABSTRACT

Tertiary fossil plants and mammals of the Clarno and Painted Hills units of the John Day Fossil beds have now been placed within a stratigraphic framework created by excavating trenches through poorly exposed parts of the sequence. The middle-late Eocene Nut Beds locality in the Clarno Formation of the Clarno area is at the top of a sequence of volcanic mudflows, that include fossil plant localities near the Hancock Tree and the Fern Quarry of about the same geological age. Reconstructions are presented here of an extinct tree *(Meliosma beusekomii)*, a tortoise (*Hadrianus corsoni*) and a variety of fossil mammals (*Telmatherium manteoceras, Hyrachyus eximius, Orohippus major, Patriofelis ferox*) from the Nut Beds, and of an extinct plane tree (*Macginitiea angustiloba*), from near the Hancock Tree. Also reconstructed are late Eocene mammals (*Protitanops curryi, Plesiocolopirus hancocki, Teletaceras radinskyi, Haplohippus texanus, Diplobunops crassus, Hemipsalodon grandis*) similar to those from the Mammal Quarry of the uppermost Clarno Formation. Newly discovered in the Clarno area but in the lower John Day Formation are fossil plants and mammals of late Eocene age. Early Oligocene lake beds of the middle Big Basin Member of the lower John Day Formation in the Painted Hills include a variety of plants, dominated by an extinct alder *(Alnus heterodonta)*, reconstructed here. Lignites stratigraphically higher within the middle Big Basin Member have yielded mostly remains of dawn redwood (*Metasequoia occidentalis*), also reconstructed here. Late Oligocene fossil mammals (*Diceratherium annectens, Miohippus quartus, "Entelodon" calkinsi, Hypertragulus hesperius, Eporeodon occidentalis, Nimravus brachyops*) from the Turtle Cove Member of the John Day Formation also are reconstructed.

INTRODUCTION

Our impressions of the prehistoric past are based less on illustrations of fossil bones and leaves than on the work of such artists as Charles Knight, Bruce Horsfall, Zdenek Burian, Jay Matternes, Frank Knight, and Peter Murray. Their restorations of past landscapes are more powerful coherent images than fragmentary fossils scattered in museum drawers and published in technical journals. Their artistry also makes obvious testable hypotheses of the nature of past life, hypotheses that can prod the search for deeper understanding. In this spirit, we offer new reconstructions of some fossil plants and animals from the Eocene-Oligocene parts of the Clarno and John Day Formations of central Oregon.

Central Oregon has long been known as an important region for Cenozoic nonmarine fossils now conserved in the John Day Fossil Beds National Monument (Figure 1). Fossil leaves were discovered in the Painted Hills by soldiers using the military road from John Day to The Dalles in the 1860s. Thomas Condon, then a missionary in The Dalles, made the first scientifically useful collections of plant and mammal fossils from the region in 1865 (Clark, 1989) and shipped them east for expert description (Marsh, 1873, 1874, 1875; Newberry, 1898; Knowlton, 1902). Expeditions from the University of California at Berkeley revisited these sites at the turn of the century and discovered plant fossils in the Clarno area (Merriam, 1901a,b, 1906; Sinclair, 1905; Merriam and Sinclair, 1907). The most significant sites in the Clarno area were first developed by amateurs, the Nut Beds by Thomas Bones, beginning in 1943 (Stirton, 1944; R.A. Scott, 1954; Bones, 1979; Manchester, 1994a), and the Mammal Quarry by Lon Hancock in 1955 (Mellett, 1969; Hanson, 1973, 1989; Pratt, 1988). The fossil riches of the area are far from exhausted, and paleontological research is still active (Retallack, 1991a,b; Manchester and Kress, 1993; Manchester, 1994a,b, 1995; Manchester and others, 1994; Meyer and Manchester, unpublished data, 1995; Fremd, 1988, 1991, 1993; Fremd and Wang, 1995). John Day fossils present striking evidence of paleoclimatic and evolutionary change on a 50-million-year time scale (Chaney, 1948a; Ashwill, 1983; Wolfe, 1992; Bestland and others, 1994). Emphasis of this paper is on their diversity and quality of preservation that allows an unusually detailed view of plants and animals on land in the distant geological past.

EOCENE FOSSILS OF THE CLARNO AREA

The geological sequence of fossil localities in the type area of the Clarno Formation near Clarno has remained unclear until recently because of the complicating effects of a local dacite intrusion and poor outcrop of clayey strata in badlands and grassy slopes. We addressed both problems by digging trenches to improve exposure and found, for example, that the dacite intrusion has a capping paleosol, so that it was a volcanic hill onlapped by fossiliferous rocks of the upper Clarno Formation (Bestland and Retallack, 1994a; Bestland and others, 1994, 1995). Such stratigraphic data, together with recent single-crystal $^{40}Ar/^{39}Ar$ radiometric dates (by C.C. Swisher for Bestland and Retallack, 1994a) have enabled us to establish the stratigraphic order of fossil localities near Clarno (Figure 2).

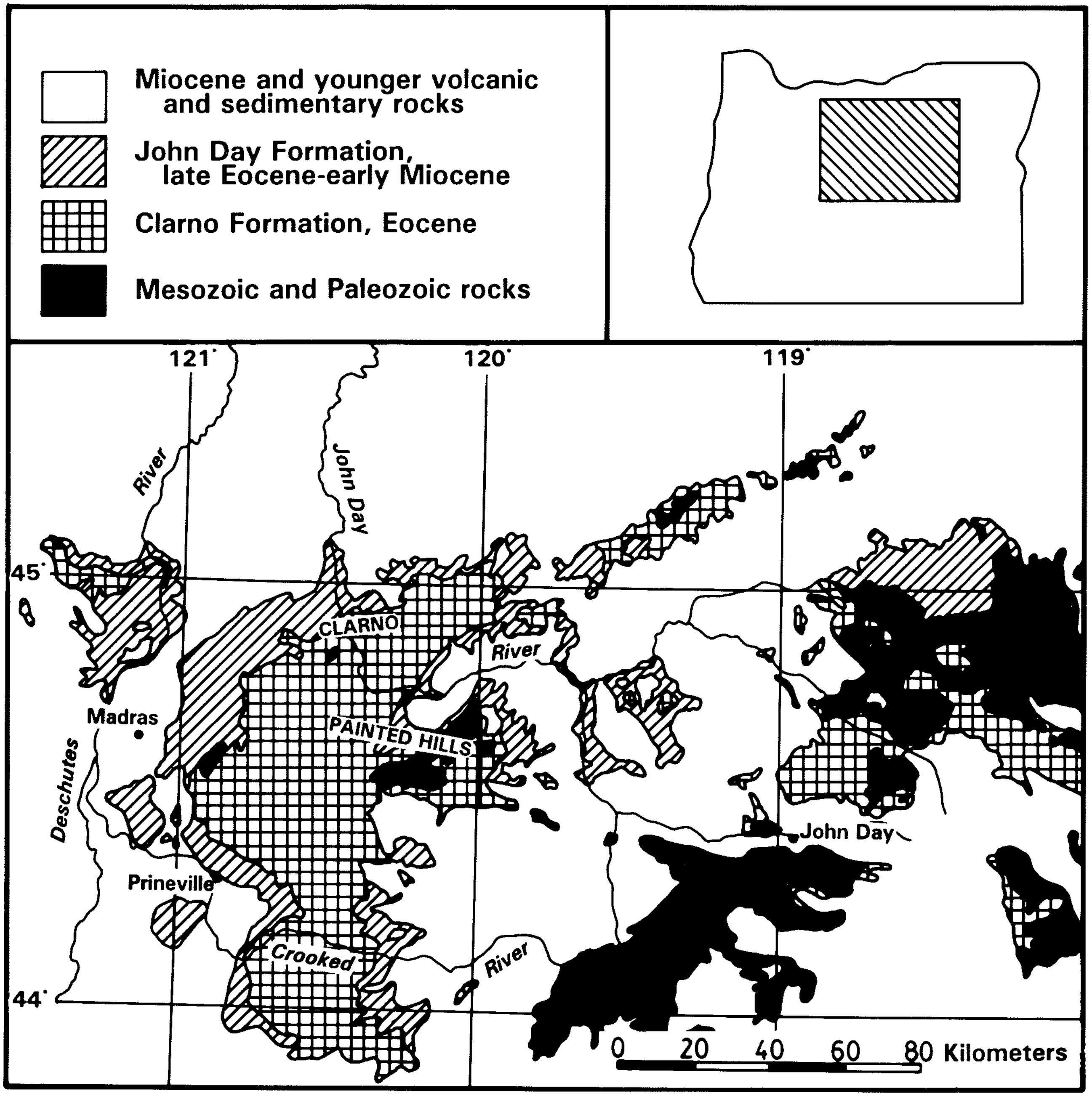

Figure 1. Location map for Painted Hills and Clarno Units of the John Day Fossil Beds National Monument, showing distribution of Clarno and John Day Formations and older rocks (after Walker, 1977; Walker and Robinson, 1990).

The best known fossil locality in this area is one known as the Clarno Nut Beds, named for an extraordinary diversity of 173 species of fossil fruits and seeds (Manchester, 1994a), fossil wood, leaf impressions, and insects (R.A. Scott, 1954, 1955, 1956; R.A. Scott and Barghoon, 1956; R.A. Scott and others, 1962; Gregory, 1969; Manchester, 1977, 1979, 1980a,b, 1981, 1983, 1987, 1988, 1991; Manchester and Kress, 1993). The diversity of the flora, its vines, bananas, palms, and other taxa, has been regarded as evidence of multistratal rain forest (Manchester, 1994a). However, associated paleosols are Ultisols (Smith, 1988; Bestland and Retallack, 1994a) rather than the Oxisols typical under equatorial rain forest or "high evergreen selva" (of Gómez-Pompa, 1973). A better modern analog considering the palms, cycads, tree ferns, oaks, planes, and laurels in the fossil flora may be the "high semi-evergreen montane selva of Lauraceae" of tropical Mexico (Gómez-Pompa, 1973). Vertebrate fossils found in the conglomerates of the Nut Beds include tortoise (*Hadrianus* sp. indet.), crocodilian, titanothere (*Telmatherium* sp. indet.), four-toed horse (*Orohippus major*), extinct rhino (*Hyrachyus eximius*), and lionlike extinct carnivore (*Patriofelis ferox*)

(Hanson, 1973; Pratt, 1988). Such a fauna is compatible with a forested habitat and middle Eocene (Bridgerian) age. Late Eocene (Uintan) is indicated by recent radiometric determinations of 43.6 and 43.7 Ma by Vance (1988), using fission tracks, and of 43.7 Ma by Turrin (for Manchester, 1994a), using single-crystal laser-fusion $^{40}Ar/^{39}Ar$ on plagioclase crystals. Most of the fossil mammals listed are known also from the Uintan, and there remain problems with the Uintan-Bridgerian boundary (Prothero and Swisher, 1992; Evanoff and others, 1994). A more precise determination than "Bridgerian-Uintan" will have to await further studies of the Wyoming type section and the Clarno fossils.

The relationship of the Nut Beds to other nearby localities has been problematic (Retallack, 1981). On the basis of our correlation of rhyodacitic ashes, unusually thick lahars, and a distinctive amygdaloidal basalt, we place the Nut Beds at the top of the volcanic mudflows in the Clarno Formation. These thick lahars with few and weakly developed paleosols accumulated rapidly, so that the numerous fossil plant localities now known to underlie the Nut Beds are not much different in geologic age. This idea is supported by fission track dates of 44 Ma for the Muddy Ranch tuff and of 44.3 Ma from a dacite cobble in a lahar above the Fern Quarry (Vance, 1988). The dacite cobble was probably derived from the onlapped local dacite dome, which is older than any known Eocene fossil locality in this area. The Muddy Ranch tuff is within a clayey sequence of paleosols between the conglomerates of the Palisades and the overlying conglomerates of Hancock Canyon, which are capped by the Nut Beds.

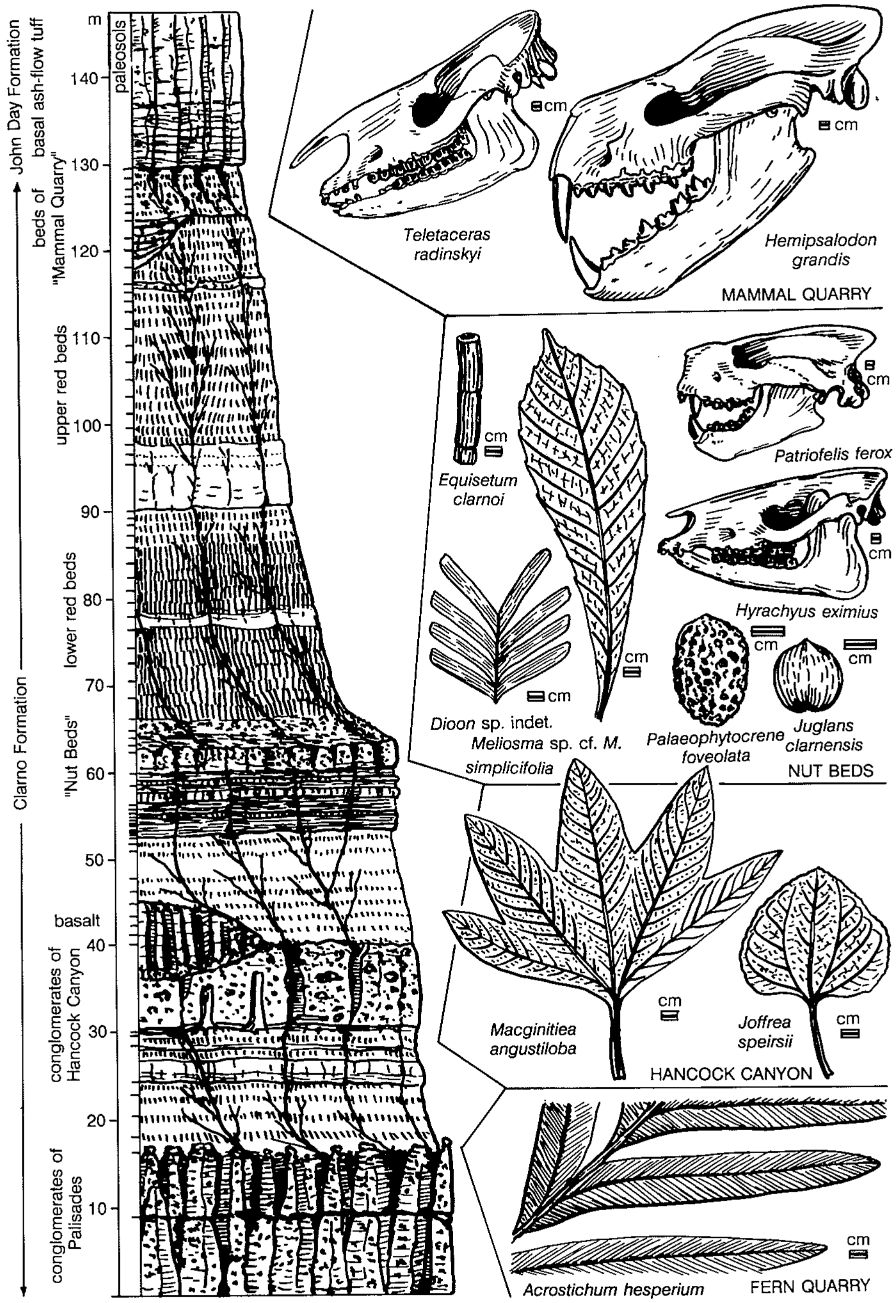

Figure 2. Geological section and fossil assemblages of the upper Clarno Formation in the Clarno Unit of the John Day Fossil Beds National Monument (illustrations adapted from Chaney, 1937; R.A. Scott, 1954; MacGinitie, 1969; Mellett, 1969; Brown, 1975; Manchester, 1981, 1986; Crane and Stockey, 1985; Savage and Long, 1986).

A newly discovered locality for lignites is within the lahar sequence, buried within the slope beneath the amygdaloidal basalt, 1 km northeast of the Oregon Museum of Science and Industry (OMSI) Hancock Field Station (Bestland and Retallack, 1994a). The thick, peaty surface horizon, associated fossil logs, and tabular systems of thick carbonaceous fossil roots are evidence of swamp forest dominated by dicotyledonous angiosperms. These are preserved in the paleosols as leaf compressions and include laurels (*Litseaphyllum presanguinea*, *Cinnamomophyllum* sp. cf. "*Cryptocarya*" *eocenica*) and aguacatilla (*Meliosma* sp. cf. *M. simplicifolia*), as well as fragments of a broad-leaved grass or sedge (*Graminophyllum* sp.) and a fern (*Anemia grandifolia*). The dominance of this swamp by dicots is most like swamps of central America south of Mexico (Breedlove, 1973; Porter, 1973; Hartshorn, 1983). In northern Mexico and the United States, in contrast, swamps are dominated by conifers such as bald cypress (*Taxodium distichum*) (Best and others, 1984). The dominance of swamps of temperate to subtropical climates by taxodiaceous conifers can be traced back in the fossil record at least into Late Cretaceous times (Retallack, 1994b).

The Fern Quarry also is within the lahar sequence of the upper Clarno Formation. Its fossil plants include mainly ferns (*Acrostichum hesperium*) with lesser horsetails (*Equisetum clarnoi*) and dicots (*Joffrea speirsii*, *Quercus* sp., *Cinnamomophyllum* sp. cf. "*Cryptocarya*" *eocenica*). Ferns and horsetails are in growth position, dicots in leaf litters of very weakly developed volcaniclastic paleosols. This herbaceous and shrubby vegetation may have been early in the ecological succession to colonize volcanic ash (Burnham and Spicer, 1986).

The Hancock Tree is a local landmark in Hancock Canyon and is part of an extensive fossil forest within the lahars of the upper Clarno Formation (Manchester, 1986). It is 39 cm in diameter and shows a 279-cm length of exposed trunk above a concealed basal portion of 115 cm to the base of the lahar and 28 cm to the top of the paleosol in which it is rooted: a total preserved length of 422 cm. The Hancock tree has 59 annual rings as well as another 12 mm too deformed to count in its 39-cm diameter. Six other prone fossil logs within the lahar had diameters of 32, 9, 7, 6, 6, and 3 cm. These were thus tall colonizing forests, intermediate between secondary regrowth and old-growth forest. Fossil leaf litters have been recovered from paleosols supporting the permineralized trunks; they include mainly temperate elements such as sycamore (*Macginitiea angustiloba*), katsura (*Joffrea speirsii*), and alder (*Alnus clarnoensis*), with few tropical elements such as laurel (*Cinnamomophyllum* sp. cf. "*Cryptocarya*" *eocenica*). In contrast, leaf litters of a weakly developed paleosol in conglomerates underlying the Nut Beds to the east yielded mainly tropical elements such as aguacatilla (*Meliosma* sp. cf. *M. simplicifolia*) and magnolia (*Magnolia* sp. cf. *M. leei*) with less common walnut (*Juglans* sp. indet.) and sycamore (*Macginitiea angustiloba*). Similarly, paleosols so weakly developed that bedding has persisted within the Nut Beds include aguacatilla (*Meliosma* sp. cf. *M. simplicifolia*), moonseed (*Diploclisia*), icacina vine (*Goweria dilleri*), magnolia (*Magnolia leei*), laurels (*Litseaphyllum praesanguinea*, *L. praelingue*, *L.* sp. cf. "*Laurophyllum*" *merrilli*, *Cinnamomophyllum* sp. cf. "*Cryptocarya*" *eocenica*), tree fern (*Cyathea pinnata*), horsetail (*Equisetum clarnoi*), walnut (*Juglans* sp.), maple (*Acer clarnoense*), alder (*Alnus clarnoensis*), katsura (*Joffrea speirsii*), and sycamore (*Macginitiea angustiloba*). Again, to the east, very weakly developed paleosols have leaf litters of temperate climatic affinities, including leaves of sycamore (*Macginitiea angustiloba*), katsura (*Joffrea speirsii*), alder (*Alnus clarnoensis*), laurel (*Litseaphyllum presanguinea*), and horsetail (*Equisetum clarnoi*). These leaf litters of both weakly and very weakly developed paleosols in the two areas represent an ecotone between two distinct kinds of ancient colonizing forest. *Meliosma* today includes species of colonizing forests (van Beusekom and van de Water, 1989), as do living sycamore (*Platanus*) (Peattie, 1991; Manchester, 1986) and alder (Burger, 1983). Vegetation comparable to the *Macginitiea*-dominated fossil assemblages in the eastern part of the OMSI Hancock Field Station is deciduous tropical forest dominated by *Liquidambar macrophylla* found at elevations of 1,000–2,000 m on volcanoes in tropical Mexico (Gómez-Pompa, 1973). *Meliosma*-dominated assemblages in the western part of the OMSI Hancock Field Station were probably comparable to pioneering forests of lowland evergreen rain forest of Mexico ("selva" of Gómez-Pompa, 1973). Such a reconstruction of deciduous forest on volcanic footslopes to the east and semi-evergreen forest on volcanic toeslopes to the west is compatible with a reconstructed Clarno paleogeography of an andesitic stratocone source for lahars to the east of the study area (White and Robinson, 1992). High-elevation deciduous Eocene plants became increasingly important for the evolution of Oligocene and younger cool-temperate deciduous floras of North America (Wolfe, 1987).

The Mammal Quarry is close to the upper contact of the Clarno Formation with the basal ash-flow tuff (member A) of the John Day Formation, which has now been radiometrically dated at 39.22±0.03 Ma, using single-crystal $^{40}Ar/^{39}Ar$ dating (Bestland and Retallack, 1994a). Thus it includes the oldest known mammalian fauna of the Duchesnean North American Land Mammal "Age" (Lucas, 1992). Very weakly developed paleosols and closely associated fluvial deposits in the quarry have yielded crocodilians, creodont carnivores (*Hemipsalodon grandis*), sabre-tooth cats (Nimravidae gen. et sp. indet.), rodents (gen. et sp. indet.), anthracotheres (*Heptacodon* sp. indet), oreodons (*Diplobunops* sp. indet.), rhinoceroses (*Teletaceras radinskyi* and cf. "*Procadurcodon*" sp. indet.), tapirs (*Plesiocolopirus hancocki* and *Protapirus* sp. indet.), and horses (*Epihippus gracilis* and *Haplohippus texanus*) (Mellett, 1969; Hanson, 1973, 1989; Schoch, 1989; Lucas, 1992). Some of these creatures, particularly the common small rhinoceros (*Teletaceras radinskyi*), evidently died locally, because they are represented by moderately complete though disarticulated specimens. Their carcasses accumulated on a fluvial point bar as isolated elements or groups of bones still united by flesh (Pratt, 1988).

Also found in the Mammal Quarry was a fossil flora of fruits and seeds (McKee, 1970; Manchester, 1994a), including tropical vines (*Odontocaryoidea nodulosa*, *Diploclisia* sp. indet., *Eohypserpa* sp. indet., *Iodes* sp. indet., *Iodicarpa* sp. indet., *Palaeophytocrene* sp. cf. *P. foveolata*, *Ampelocissus* sp. indet., *Vitis* sp. indet., *Tetrastigma* sp.), sycamores (*Platananthus synandrus*), dogwoods (*Mastixioidiocarpum oregonense*), alangiums (*Alangium* sp. indet.), cashews (*Pentoperculum minimus*), and walnuts (*Juglans clarnensis*). Late Eocene mammals here evidently lived in forests, but Luvisol paleosols in association with these fossils are evidence for a cooler and drier climatic regime than during deposition of the Nut Beds (Bestland and Retallack, 1994a).

New fossil localities were also discovered within the lower John Day Formation in footslopes of Iron Mountain, stratigraphically below a distinctive thick tuff radiometrically dated (using the single-crystal laser-fusion $^{40}Ar/^{39}Ar$ technique) at 38.4±0.07 Ma (C. Swisher for Bestland and Retallack, 1994a). This is still within the late Eocene and Duchesnean (Swisher and Prothero, 1990). From a red paleosol described by Getahun and Retallack (1991) immediately below the dated tuff came a fragment of a tusk, probably of the extinct family of hoglike Entelodontidae, and a molar of the small Clarno rhino *Teletaceras radinskyi*. Brown lake beds with fish scales some 5 m below the tuff have yielded winged fruits of walnutlike plants (*Cruciptera simsoni*, *Palaeocarya clarnensis*), fruits of eucommia (*Eucommia* sp. indet.), extinct malvalean flowers (*Florissantia ashwillii*), seeds of cigar-tree (*Catalpa* sp. indet.), and leaves of elm (*Ulmus* sp. indet.), Oregon grape (*Mahonia* sp. indet.), and dawn redwood (*Metasequoia occidentalis*) (Bestland and Retallack, 1994a; S.M. Manchester, oral commun., 1995). This flora and associated Luvisol paleosols are evidence for forests of lesser stature, more open and deciduous than earlier in the Eocene.

The "Slanting Leaf Beds" is a well-known locality higher within the John Day Formation in the Clarno area and now radiometrically dated at 33.62±0.19 Ma (Swisher for Bestland and Retallack, 1994a), which is very early in the Oligocene (Swisher and Prothero, 1990). These tuffaceous lacustrine beds have yielded a very different fossil flora dominated by alder (*Alnus heterodonta*) and dawn redwood (*Metasequoia occidentalis*). This is one of the many Bridge Creek floras especially well known near Fossil and in the Painted Hills (Manchester and Meyer, 1987; Kvacek and others, 1991; Manchester, 1992; Meyer and Manchester, unpublished data, 1995). The dramatic floral change from floras of tropical to those of temperate climatic affinities is reflected in a change in paleosols from red Luvisols to a mix of Inceptisols, Vertisols and Luvisols (Bestland and Retallack, 1994a), also seen in the Painted Hills.

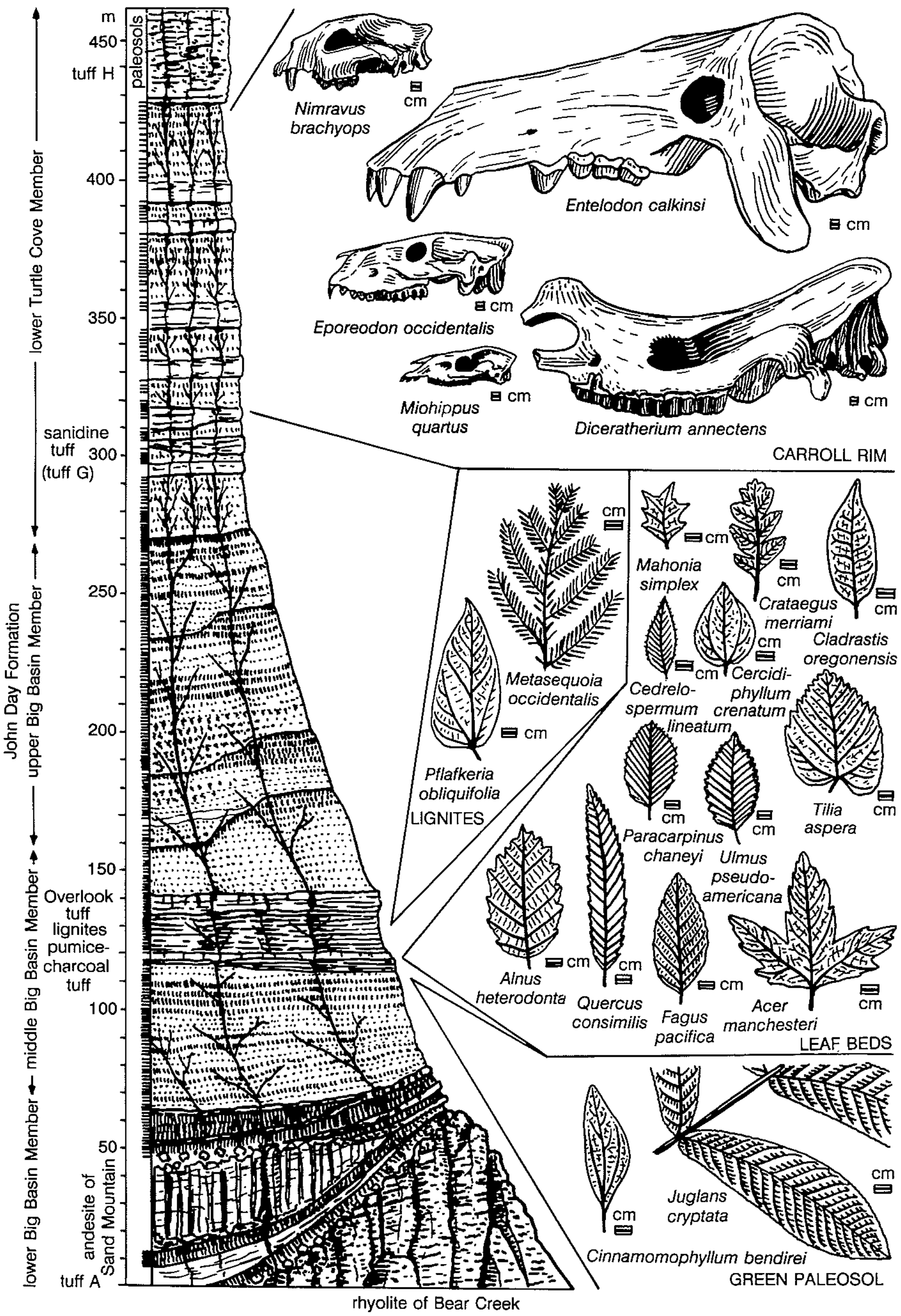

Figure 3. Geological section and fossil assemblages of the lower John Day Formation in the Painted Hills Unit of the John Day Fossil Beds National Monument (illustrations adapted from Knowlton, 1902; Sinclair, 1905; Osborn, 1918; Peterson, 1920; Toohey, 1959; Lander, 1977; Tanai and Wolfe, 1977; Wolfe and Tanai, 1987; Meyer and Manchester, unpublished data, 1995).

OLIGOCENE FOSSILS OF THE PAINTED HILLS

The principal fossil resources protected by the Painted Hills Unit of the John Day Fossil Beds are the lake beds with leaves of the Bridge Creek flora (Figure 3), first collected by Thomas Condon in 1865 for Newberry (1898) and Knowlton (1902) and then made famous by pioneering papers in quantitative paleoecology by Chaney (1924, 1925a). Dominance of these shales by plants of temperate climatic affinities such as oak (*Quercus consimilis*), alder (*Alnus heterodonta*), and dawn redwood (*Metasequoia occidentalis*) is in striking contrast to the tropical affinities of fossil plants in the Clarno Formation (Chaney, 1948a). At first, Chaney (1924, 1938) compared the assemblage with that of redwood forests of California. When it was discovered in 1941 that dawn redwood was still living in China, Asian mixed mesophytic forests became a better model (Chaney, 1948a,b, 1952, Wolfe, 1981, 1992; Manchester and Meyer, 1987). In contrast, our new collections indicate that *Metasequoia* was a swampland tree.

One problem with leaves in lake beds is the way in which elements of different plant communities are mixed with and overwhelmed by deciduous lake-margin species. We have been able to demonstrate such biases in the Bridge Creek flora with new collections of plants from leaf litters of paleosols associated with the lake beds (Bestland and Retallack, 1994b). A small fossil flora of leaves found in the surface horizon of a weakly developed green paleosol underlying the lake beds included dawn redwood (*Metasequoia occidentalis*), nutmeg tree (*Torreya* sp. indet.), grass (*Graminophyllum* sp. indet.), laurel (*Cinnamomophyllum bendirei*), and walnut (*Juglans cryptata*). Remains of walnuts were most common, followed by the laurels. The dawn redwood is represented by only one foliar spur. The paleosol and plants combined indicate semi-evergreen mesophytic forest of bottomlands. A very different assemblage was found in a manganese-stained shale overlying a very weakly developed paleosol within the lake beds: mainly leaves of alder (*Alnus heterodonta*) with oak (*Quercus consimilis*) and yellowwood (*Cladrastis oregonensis*). Alders in particular are well-known pioneer plants of disturbed ground, both in tropical and temperate regions (Burger, 1983), and this interpretation is supported by the minimal development of the fossil soil. Lignitic paleosols overlie a pumice-charcoal tuff above the lake beds. These ancient soils of swamps are overwhelmingly dominated by dawn redwood (*Metasequoia occidentalis*), associated with rare bracken fern (*Pteridium calabazensis*), grass (*Graminophyllum* sp. indet.), alder (*Alnus heterodonta*), and extinct basswood (*Plafkeria obliquifolia*). These paleosol assemblages indicate that the Bridge Creek flora of lacustrine shales is a mix of at least three distinct plant communities: semi-evergreen lowland laurel forest, dawn redwood swamp, and deciduous alder pole woodlands.

The age of the Bridge Creek flora in the Painted Hills is constrained by new single-crystal laser-fusion $^{40}/Ar^{39}Ar$ radiometric dates of 32.99±0.11 Ma for a biotite tuff below the lake beds and 32.66±0.03 Ma for tuffs above the lake beds and lignites, both within the middle Big Basin Member of the John Day Formation (C.C. Swisher for Bestland and Retallack, 1994b). Like the "Slanting Leaf Beds" of the Clarno area, these also are earliest Oligocene in age. At some time between 33 Ma and the 38-Ma fossil flora from the Clarno area discussed above, there was a climatic deterioration from mean annual precipitation of 1,500 mm to 1,000 mm (Leopold and others, 1992), from mean annual temperature of 20°C to 12°C, and from mean annual range of temperature of 10°C to 25°C (Wolfe, 1992). A comparable deterioration to temperate climate is indicated by the transition from kaolinitic and iron-rich, red, lateritic Ultisol and Luvisol paleosols of the lower Big Basin Member of the John Day Formation, which are erosionally truncated and abruptly overlain by smectitic and tuffaceous Inceptisol, Vertisol, and Luvisol paleosols of the middle Big Basin Member (Bestland and others, 1994, 1995, 1996). The erosional contact probably corresponds to the Eocene-Oligocene boundary now recognized at 34 Ma (Swisher and Prothero, 1990), judging from radiometric dates from underlying units: a new $^{40}Ar/^{39}Ar$ single-crystal radiometric date of 39.72±0.03 Ma for the basal ash-flow tuff of the John Day Formation (C.C. Swisher for Bestland and Retallack, 1994b) and a date of 37 Ma for the andesite of Sand Mountain (Hay, 1963; Evernden and James, 1964). Our correlation of these units and assessment of the degree of development of lateritic paleosols of the lower John Day Formation suggest that the Eocene-Oligocene climatic deterioration was abrupt (Retallack, 1992; Rice, 1994; Bestland and others, 1996).

The badlands of Carroll Rim in the Painted Hills and the nearby footslopes of Sutton Mountain have yielded only sparse and fragmentary mammal fossils from the Turtle Cove Member below the massive ash-flow tuff of Carroll Rim ("Picture Gorge tuff" or Member H of Robinson and others, 1984). The Turtle Cove Member here is dated by new determinations of 29.75±0.02, 29.70±0.06, 28.65±0.05, and 28.65±0.07 Ma on tuffs and the cliff-forming ash flow (last two dates), respectively (C.C. Swisher for Bestland and Retallack, 1994b). Comparable late Oligocene (early Arikareean) fossil mammals are more abundant and better known from the Turtle Cove Member in the John Day Valley south of Kimberly (Fremd, 1988).

Fossil mammal fragments were mainly found in paleosols and can be grouped by paleosol type. Some of these have brown, finely structured, near-mollic surface horizons over a subsurface horizon of calcareous nodules, as in soils now supporting grassy woodland and wooded grassland. Fossil mammals in these paleosols include mouse deer (*Hypertragulus hesperius*), oreodonts (Merycoidontidae gen. et sp. indet.), and rhinoceros (*Diceratherium* sp. cf. *D. annectens*). Other paleosols are comparable in their brown, finely structured surface horizons, but lack nodules, which indicates a shorter time for formation but comparable vegetation. Mammals of these paleosols include an unidentifiable mammalian navicular, a distal phalanx of an oreodont (Merycoidodontidae), and a cuboid similar to that of a giant, hoglike entelodon (cf. *Entelodon* sp. indet.). Very weakly developed paleosols probably supported streamside grassy vegetation early in ecological succession to communities represented by the other paleosols. Mammals of these transient communities include extinct squirrel-like rodent (Eutypomyidae gen. et sp. indet.), oreodon (*Agriochoerus* sp. indet., *Eporeodon* sp. indet.), three-toed horse (*Miohippus* sp. cf. *M. quartus*), and two-horned rhinoceros (*Diceratherium* sp. cf. *D. annectens*). Other paleosols are green and clayey with subsurface calcareous nodules and probably supported seasonally wet alluvial grassy woodland. Comparable paleosols near Foree to the east have yielded oreodont (*Eporeodon occidentalis*), three-toed horse (*Miohippus* sp. cf. *M. anceps*), and foxlike dog (*Mesocyon coryphaeus*). No red, clayey paleosols were seen in the Turtle Cove Member of the Painted Hills, but red paleosols in Rudio Creek canyon near Kimberly yielded three-toed horse (*Miohippus equiceps*). Although endocarps of hackberry (*Celtis willistoni*) (Cockerell) Berry 1928 (Chaney 1925b) are the only plant fossils found in the Turtle Cove Member, paleosols indicate a mosaic of woodland in hills and footslopes, wooded grassland and grassy woodland in valley bottoms, and local grassy woodlands in seasonally wet bottomlands. Mammalian collections from particular paleosols are as yet inadequate to demonstrate their ecological preferences. Nevertheless, the paleoenvironmental reconstruction from paleosols is compatible with the mix of arboreal squirrels, browsing horses and oreodonts, and grazing rhinos, similar to assemblages in the Great Plains regarded as adapted to grassy woodland and wooded grassland (Webb, 1977; MacFadden, 1992; Prothero and others, 1996).

Paleosols of the Turtle Cove Member indicate much drier and probably also cooler paleoclimatic conditions than earlier in the Oligocene. Depth to the calcareous nodules is strongly correlated with mean annual rainfall in modern soils (Retallack, 1994a), and application of these relationships with allowances for compaction of paleosols in Carroll Rim gives mean annual rainfall of 614±141 mm to 911±141 mm (Bestland and Retallack, 1994b). This range of about 500–1,000 mm for the Turtle Cove Member can be compared to 800–1,000 mm for the upper Big Basin Member and 1,000–1,200 mm for the middle Big Basin Member, derived by comparison with comparable soils in Mexico (Bestland and Retallack, 1994b). Paleoclimatic drying continued into the early Miocene, judging from our reconnaissance observations of the upper John Day Formation on Sutton Mountain. The John Day Formation preserves a long-term paleoclimatic record that complements and correlates well with the geological record of global change in deep-sea cores (Bestland and Retallack, 1994b).

RECONSTRUCTED FOSSIL PLANTS

An outstanding advantage of preservation of plants in paleosols is the lack of mixing and separation of different parts of different plants. The leaves, fruits, flowers, and wood are preserved near their place of growth, little mixed by transport in streams or drifting off into lake beds. Such fossiliferous paleosols are known in the lower part of the Clarno Nut Beds and within the lignites and lake beds of the Painted Hills, and they make easier the difficult task of reconstructing ancient plants from a jumble of different plant remains (Manchester, 1981). Physical attachment of one part of a plant to another, such as fruits on leafy twigs, is the most compelling, but unfortunately rare, evidence for reconstructing fossil plants. Comparison with modern plants is also useful, particularly if there is only one fossil species of fruit, wood, flower, and leaf comparable to a particular modern plant. In this way, it is hoped to gain a complete concept of particular ancient plants and their evolution. As this work proceeds, it is revealing that some parts of plants such as fruits and seeds evolve at rates different from others such as wood and leaves (Manchester, 1986, 1987; Manchester and Wheeler, 1993). This mosaic evolution not only explains differing interpretations of ancient vegetation based on wood, fruits, and leaves but is of interest for understanding the evolutionary process itself.

Meliosma beusekomii

Meliosma beusekomii Manchester (1994a) is a middle Eocene fossil species named for fruits common in the Clarno Nut Beds of the Clarno Formation (Figure 4). The fruits are drupes, but the preserved parts are characteristically dimpled stones or endocarps (Manchester, 1994a). *Meliosma beusekomii* endocarps are very similar to those of living species such as *M. pinnata* and *M. simplicifolia*. Leaves comparable to *M. simplicifolia* also are common in the Nut Beds and in other fossil leaf litter assemblages of the upper Clarno Formation (Manchester, 1980b). Our reconstruction of the shoot with fruits and leaves is based on that of *M. simplicifolia* (van Beusekom and van de Water, 1989). Wood of *Meliosma* has also been found in the Nut Beds (Manchester, 1980b) and was sketched from photomicrographs generously supplied by Steven Manchester.

The large leaves (up to 21 cm long) of this extinct Eocene species of *Meliosma* have a pronounced drip tip, as is typical for plants of tropical rainy climates. *Meliosma* today is widespread in the humid tropics and subtropics of eastern Asia, Indonesia, Central America, and the West Indies (Gentry, 1980; van Beusekom and van de Water, 1989). *Meliosma* includes both shrubs and trees, and its family Sabiaceae includes vines (Gentry, 1980). Permineralized fossil wood of *Meliosma* is known only as waterworn fragments but is evidence that *M. beusekomii* was a tree. It probably was not a large tree, because its leaves dominate the litters of very weakly developed paleosols that lack large root traces or differentiated soil horizons. These paleosols in the Nut Beds and elsewhere are associated with fluvial facies (Retallack, 1991a), so that *M. beusekomii* can be envisaged a pole tree of woodlands early in ecological succession of recovery from stream flooding.

Macginitiea angustiloba

Macginitiea angustiloba (Lesquereux) Manchester

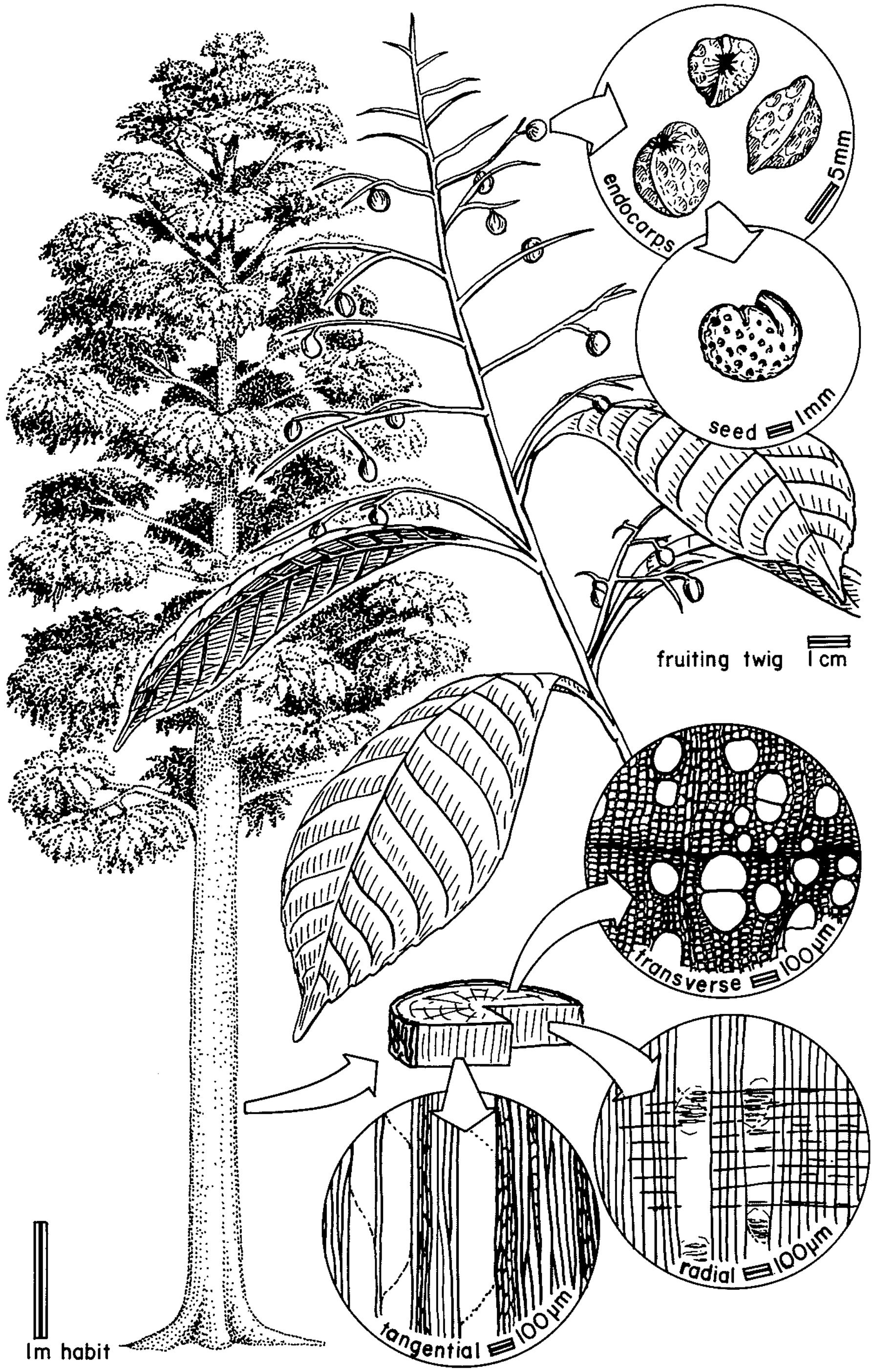

Figure 4. Reconstruction of a fossil aguacatilla (Meliosma beusekomii) *from the middle-late Eocene "Nut Beds" of the Clarno Formation at Hancock Field Station (data from Bones, 1979; Manchester, 1981, 1994a; van Beusekom and van de Water, 1989).*

(1986) is the name of a palmately lobed leaf common in lahars of Hancock Canyon and elsewhere in the Eocene Clarno Formation (Figure 5). The leaf is similar to those of living sycamores and planes (*Platanus*). The Hancock tree is a well-known local landmark in Hancock Canyon and is a katsura (*Joffrea speirsii*) (Retallack, 1991a), but the other common species within the same paleosol is *Macginitiea angustiloba*. Stumps of *Macginitiea angustiloba* are recognizable in hand specimen by their characteristic wide rays, and this wood has been referred to *Plataninium haydenii* (Wheeler and others, 1977; R.A. Scott and Wheeler, 1982). The globose pistillate and staminate heads and isolated anthers of this plant have also been given separate names, *Macginicarpa glabra*, *Platananthus synandrus*, and *Macginistemon mikanoides*, respectively (Manchester, 1986), in the widely used organ–generic procedure of paleobotany. There is little doubt from their joint association in numerous localities, including lake beds and fluvial sandstones as well as the paleosols of Hancock Canyon and the Nut Beds, that these represent parts of the same extinct species of sycamore-like plant (Manchester, 1986).

Like modern sycamores, *Macginitiea angustiloba* had leaves with abscission scars, indicating it was deciduous. Its separate pistillate and staminate flowering heads produced abundant small (16–18 μ) pollen and small (6–8 mm), hard fruits, which are indications that it was pollinated and dispersed by wind and water (Manchester, 1986). *Macginitiea angustiloba* had slightly smaller pollen, better developed perianth, and more consistently pentamerous flowers than modern sycamores, which may indicate facultative unspecialized insect pollination or an evolutionary legacy of insect pollination. *Macginitiea angustiloba* also lacked hairs that facilitate wind dispersal of fruits of living sycamores. This combination of largely wind and water pollination and dispersal with some hints of facultative animal involvement are common in plants that colonize disturbed ground. Like living sycamores (*Platanus*), many comparable fossils as old as Cretaceous also were trees of disturbed streamsides (Retallack and Dilcher, 1981). Such an ecology for the Clarno plant is indicated in Hancock Canyon, where trunks attributed to *Macginitiea angustiloba* are rooted in a weakly developed paleosol capping fluvial deposits interbedded with lahars (Bestland and Retallack, 1994a). *Macginitiea angustiloba* is the most prominent of several plants in the Clarno Formation that were deciduous, wind and water pollinated and dispersed, and with cool-temperate climatic affinities. Unlike diverse assemblages of the Nut Beds, low diversity fossil forests of Hancock Canyon may represent a flora of higher elevations on the volcanic cone, like the *Liquidambar* forests of San Martin Volcano in Veracruz, Mexico (Gómez-Pompa, 1973).

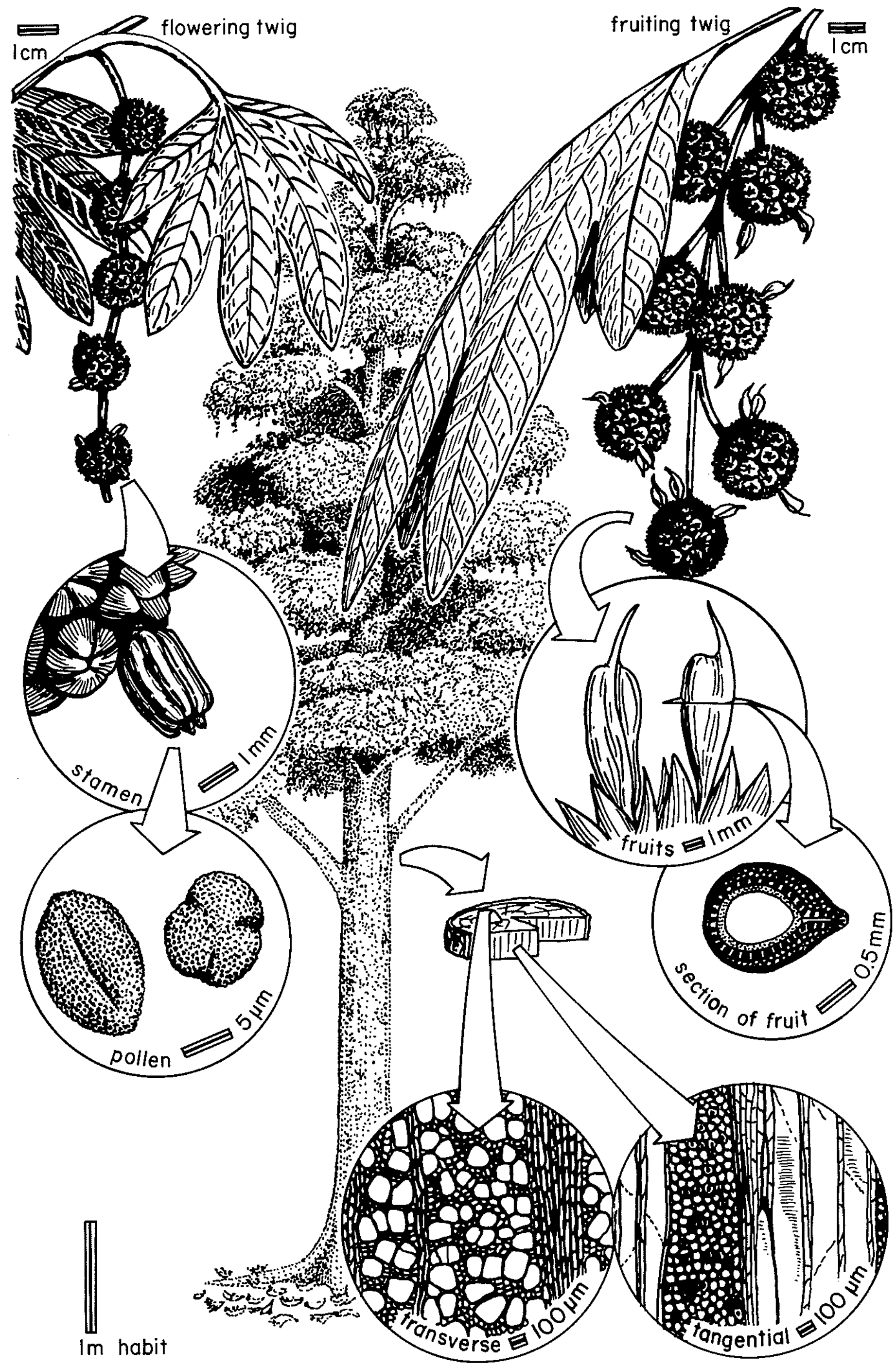

Figure 5. Reconstruction of a fossil plane (Macginitiea angustiloba) *from the middle-late Eocene conglomerates of Hancock Canyon of the Clarno Formation at Hancock Field Station, Oregon (data from Wheeler and others, 1977; R.A. Scott and Wheeler, 1982; Manchester, 1986).*

Metasequoia occidentalis

Foliage, cones, and seeds of the dawn redwood *Metasequoia occidentalis* (Newberry) Chaney (1951) are common in the Bridge Creek flora of the middle Big Basin Member of the John Day Formation at many localities, including the Painted Hills, the Slanting Leaf Beds of the Clarno area, and the well-known bank behind the High School in Fossil (Manchester and Meyer, 1987). In the Painted Hills, foliage of this plant is found in nearly monospecific assemblages with permineralized coniferous wood in a sequence of lignites. Exceptionally well preserved permineralized wood, cones, and foliage of *Metasequoia* also are known from the middle Eocene Princeton chert of British Columbia (Rothwell and Basinger, 1979; Basinger, 1981, 1984), which is a permineralized peat swamp. Although these Eocene fossils have been referred to the species *Metasequoia milleri*, they are externally identical to living dawn redwood *M. glyptostroboides*, which cannot be readily distinguished from the fossil species for leaf impressions, *M. occidentalis*. *Metasequoia milleri* differs from *M. glyptostroboides* in its higher wood rays and two additional resin canals in the distal portion of the microsporophyll of the pollen cone (Rothwell and Basinger, 1979; Basinger, 1981). Plants of peat swamps are known to evolve very slowly; for example, many species known from permineralized remains range through the entire 30 Ma of the Pennsylvanian with little evolutionary change (DiMichele and others, 1987). Similarly, *M. occidentalis*, *M. milleri*, and *M. glyptostroboides* may all represent the same long-lived species. *Metasequoia* has long been known as a living fossil, because it was discovered alive in China after description as a fossil (Chaney, 1948a). This raises the interesting procedural problem of a living genus with a fossil type specimen (Schopf, 1948).

Metasequoia has been extinct in North America since

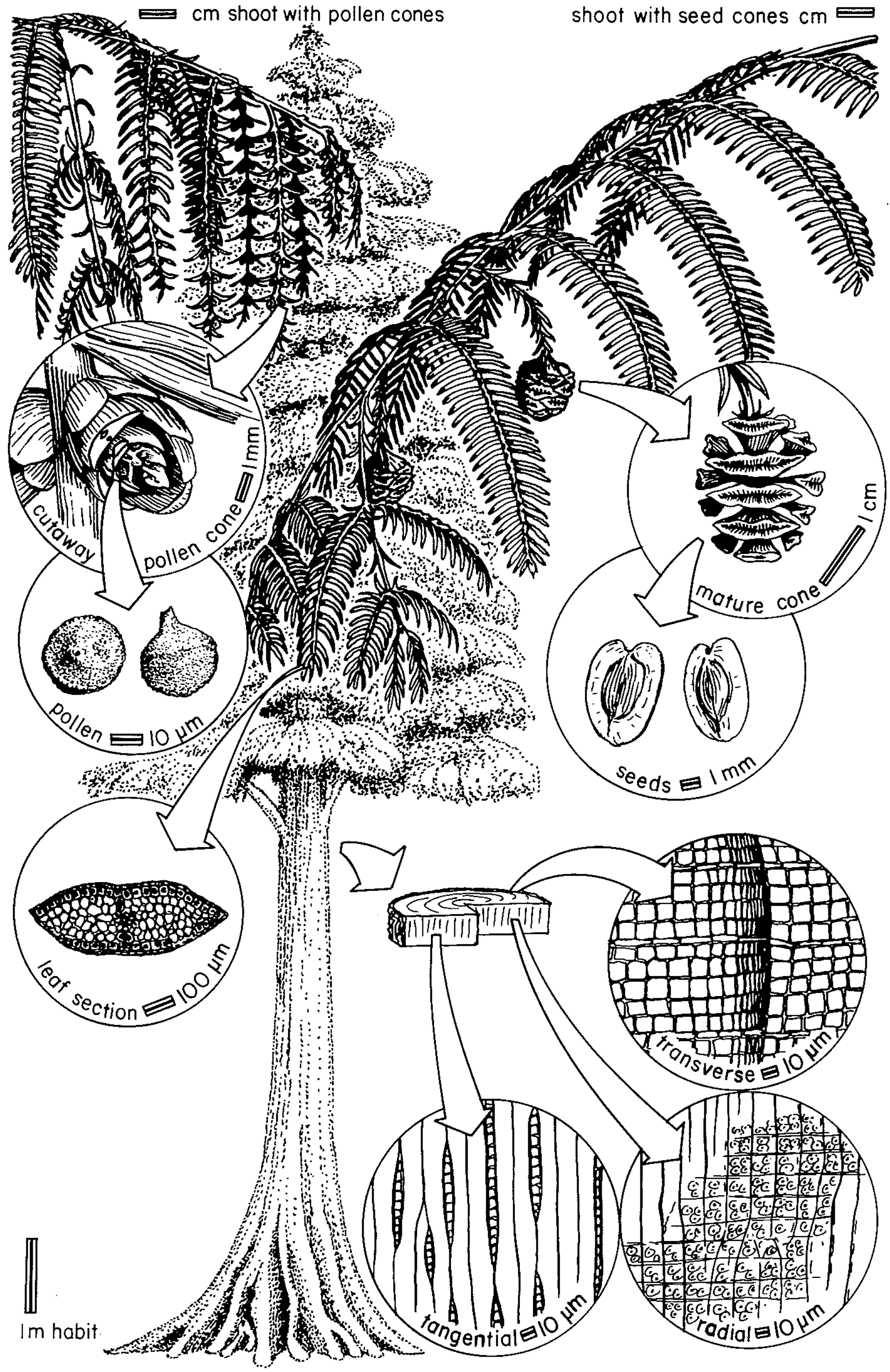

Figure 6. Reconstruction of a fossil dawn redwood (Metasequoia occidentalis) *from the early Oligocene middle Big Basin Member of the John Day Formation in the Painted Hills, Oregon (data from Merrill, 1948; Manchester and Meyer, 1987; Meyer and Manchester, unpublished data, 1995; additional details from the probably conspecific* M. milleri *of Rothwell and Basinger, 1979; Basinger, 1981, 1984).*

late Miocene time (Chaney, 1948a), and the geologically youngest fossils found anywhere are Pliocene (Miki, 1941). Several hundred *Metasequoia* trees now growing in Oregon are descended from seeds distributed by Ralph Chaney in 1950. During his visit to China in the spring of 1948, he was unable to obtain seeds, but he distributed seeds purchased from China by E.D. Merrill (1948) of Harvard's Arnold Arboretum. A particularly fine tree grown from Chaney's original distribution grows near Cascade Hall on the University of Oregon campus. It stands under the gaze of a bronze bust of Thomas Condon, who first discovered these Oregon fossils. Sketches of this tree were used for our reconstruction (Figure 6).

Metasequoia is seasonally deciduous like larch (*Larix*) and differs in this respect from most conifers, which are evergreen. The pollen cones are formed with the soft, light-green spring leaves, and the seed cones do not mature until late in the fall. Like most conifers it is wind pollinated, and seed is dispersed by wind and water. *Metasequoia occidentalis* has long been regarded as a dominant of a mixed conifer–angiosperm flora (Chaney, 1924, 1925a; Wolfe, 1981, 1992), and this has been regarded as confirmed by its occurrence in China (Chaney, 1948a, Chu and Cooper, 1950; Hu, 1980). However, this small area of northwest Hupei Province has been greatly disturbed by agriculture. *Metasequoia glyptostroboides* was found in ravines and embankments around paddy fields that have submerged at least two hundred trunks of a relatively pure stand of these plants (Bartholomew and others, 1983). Its common occurrence with angiosperm leaves in the various Bridge Creek floras could be a result of mixing in lake deposits. A new view of the natural habitat of *Metasequoia* emerges from its dominance in the lignites of the Painted Hills (Bestland and Retallack, 1994b) and permineralized peats of British Columbia (Rothwell and Basinger, 1979, Basinger, 1981, 1984). *Metasequoia occidentalis* and the likely conspecific *M. milleri* can now be seen as swamp cypresses comparable with living bald cypress (*Taxodium distichum*) of Okefenokee Swamp and the Florida Everglades (Best and others, 1984). Both *Taxodium* and *Metasequoia* are in the family Taxodiaceae, and Newberry (1883) may not have been far off the mark when he included fossils now called

Metasequoia in *Taxodium*. These modern swamps have a low diversity complement of angiosperms, and some angiosperm fossils also have been found with *Metasequoia* in the fossil peats of the Painted Hills (Bestland and Retallack, 1994b) and British Columbia (Stockey, 1987; Cevallos-Ferriz and Stockey, 1988a,b, 1989, Erwin and Stockey, 1989a,b, 1994; 1990a,b, 1991; Stockey and Pigg, 1991; Cevallos-Ferriz and others, 1993). However, these cannot be taken as representative of forests of well-drained soils away from the swamps. Much has been made of the climate of relict populations of *Metasequoia* in Hupei to infer Oligocene paleoclimate of Oregon (Chaney, 1948a). As a swamp plant, however, its paleoclimatic significance is limited, because it lived in soils isolated from regional climate by local waterlogging. Its temperature tolerances in the past were probably also cool-temperate to subtropical, like swamp cypresses today, which dominate swamps as far south as northern Mexico but are replaced by angiosperm swamps in the Central American tropics (Breedlove, 1973; Porter, 1973, Hartshorn, 1983).

Alnus heterodonta

Alder leaves and catkins are among the most common fossils in Bridge Creek floras of the middle Big Basin Member of the John Day Formation (Manchester and Meyer, 1987; Meyer and Manchester, unpublished data, 1995). Several species of alder have been recognized, even within single localities (Klucking, 1956), but *Alnus heterodonta* is the most common leaf in the Painted Hills (Figure 7). Young leaves, seeds, and staminate and fruiting catkins also are found occasionally (Meyer and Manchester, unpublished data, 1995). The attribution of all these remains to one plant is based on association and comparison with living alder.

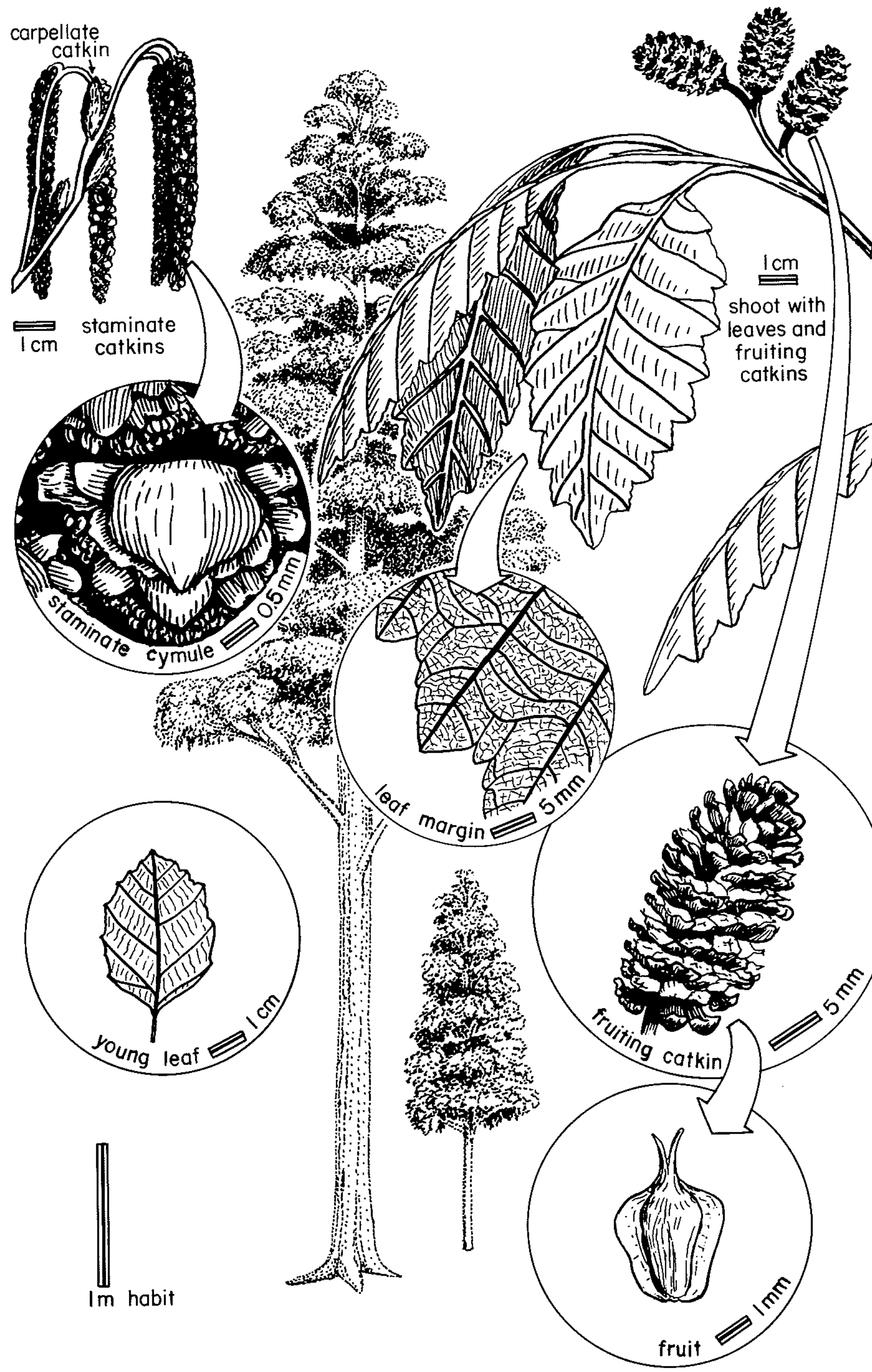

Figure 7. Reconstruction of a fossil alder (Alnus heterodonta) *from the early Oligocene middle Big Basin Member of the John Day Formation in the Painted Hills, Oregon (data from Klucking, 1956; Wood, 1974; Manchester and Meyer, 1987; Meyer and Manchester, unpublished data, 1995).*

The inconspicuous flowers, small, flattened seeds, and leaf abscission scars of the fossils are evidence that this extinct species was wind pollinated and dispersed and seasonally deciduous like living alder and others of the family Betulaceae in cool-temperate climatic regions of the northern hemisphere. Because these leaves dominate the leaf litter of a very weakly developed paleosol in the lake beds of the Painted Hills (Bestland and Retallack, 1994b), it is likely that they were plants of pole woodlands early in the ecological succession to recover disturbed ground. Such an oppor-

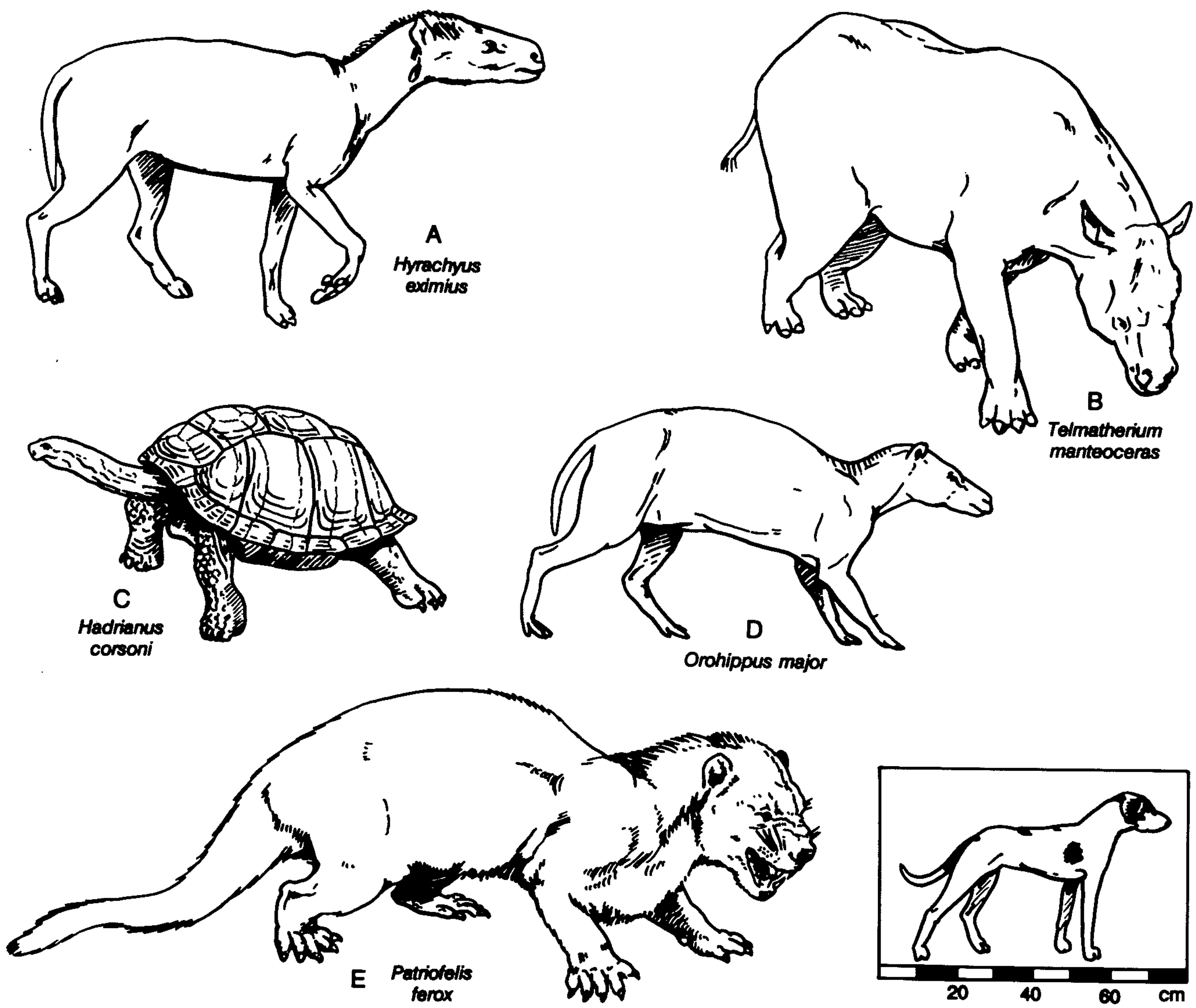

Figure 8. Reconstructions of middle-late Eocene (Bridgerian-Uintan) animals from the Nut Beds of the Clarno Formation at the OMSI Hancock Field Station, Oregon (A and scale from R.B. Horsfall for W.B. Scott, 1913; B from E.M. Fulda for Osborn, 1929; E from C.E. Knight for Osborn, 1910; others original with data from Hay, 1908).

tunistic ecology is characteristic of many alder species (Burger, 1983), including the red alder (*Alnus rubra*) of Oregon, which forms roadside and streamside pole woodlands, and extensive stands for some 50–80 years after clear-cutting or fire (Peattie, 1991). Neither the swamp-bound *Metasequoia occidentalis* nor the ephemeral *Alnus heterodonta* are likely to have been abundant in well-drained soils during Oligocene time, despite their dominance of lacustrine leaf accumulations.

RECONSTRUCTED FOSSIL ANIMALS

Complete skeletons or natural mummies of extinct animals are ideal for reconstructing their appearance and lifestyle (Savage and Long, 1986). Few of these have been found in the John Day Fossil Beds, where fleshing out the fragments must rely on more complete skeletons from other parts of North America and inferences from comparable modern mammals. Fortunately, there is a long tradition of fossil vertebrate reconstruction (Osborn, 1910; W.B. Scott, 1913). More than ever before, we have the resources to conjure up visions of extinct beasts from isolated teeth and bones.

Hadrianus corsoni

Only a fragment of this thick-shelled tortoise has been found in the middle Eocene Clarno Nut Beds, and it is not referable to a particular species. The reconstruction offered here (Figure 8C) is *Hadrianus corsoni* (Leidy) Cope (1873), represented by complete carapaces and limb bones from middle Eocene (Bridgerian) rocks south of Fort Bridger, Wyoming (Hay, 1908). The genus *Hadrianus* ranges through much of the Eocene (Wasatchian to Uintan)

(Hutchinson, 1992). These were land tortoises of the family Testudinidae, which are all herbivores and include the well-known Galapagos tortoises (*Geochelone*) (Carroll, 1988).

Telmatherium manteoceras

Molars of this brontothere are the most common vertebrate fossils in the middle Eocene Clarno Nut Beds and may represent a new species of *Telmatherium*. Our reconstruction (Figure 8B) is based on one by E.M. Fulda (for Osborn, 1929) of *Telmatherium manteoceras* (Hay) Mader (1989), known from good skulls and partial skeletons of middle Eocene (Bridgerian-Uintan) age in the Washakie and Bridger Basins of Wyoming (Osborn, 1929; Eaton, 1985). Painted reconstructions by Charles Knight (for Osborn, 1910, 1929) are very similar to this sketch. Brontotheres (also called titanotheres) are extinct perissodactyls of North America and Asia and represent a distinct evolutionary lineage from rhinoceroses which they vaguely resemble. *Telmatherium* had the low-crowned teeth of a browser, like most bronthotheres. It was small for this group, which evolved from dog-sized animals in the early Eocene to massive rhino-sized animals in the latest Eocene (Carroll, 1988).

Hyrachyus eximius

A variety of skull fragments and teeth in the Clarno Nut Beds belong to *Hyrachyus eximius* Leidy (1871), well known from relatively complete skeletons in middle to late Eocene (Bridgerian to Uintan) deposits of the Bridger and Washakie Basins of Wyoming (W.B. Scott, 1913). Our reconstruction (Figure 8A) is based on the sketch of Bruce Horsfall (for W.B. Scott, 1913), which we prefer to more stocky reconstructions by Zdenek Burian (for Spinar and Burian, 1972), Jay Matternes (for Smithsonian Institution mural, see Dott and Batten, 1981), Michael Long (for Savage and Long, 1986), and Graham Allen (for Dixon and others, 1992). Its low-crowned teeth are those of a browser, but it had padded feet like those of a tapir rather than hooves like modern ungulates. Primitive features of *Hyrachyus* include four toes on the rear limbs and prominent canine teeth. It belongs to an extinct group of mammals (Helatetidae or Hyrachyidae) allied to both tapirs and rhinos and possibly ancestral to both.

Orohippus major

The small, primitive horse *Orohippus major* Marsh (1874) is represented by several teeth and jaw fragments from the Clarno Nut Beds, but good skeletons have been found in the middle Eocene (Bridgerian) of the Bridger Basin of Wyoming (Kitts, 1957). Our reconstruction (Figure 8D) is based on one by Charles Knight (for Osborn, 1910), although others have been done by Zdenek Burian (for Spinar and Burian, 1972) and Jay Matternes (for Smithsonian Institution mural, see Dott and Batten, 1981). With its low-crowned teeth of a browser and four toes on the front limbs and three toes in the rear, this very small horse is far removed from our modern concept of a horse (MacFadden, 1992). These early forest-dwelling ancestors of modern Equidae lack exact modern analogs.

Patriofelis ferox

Patriofelis ferox (Marsh) Marsh (1878) is represented by a single jaw fragment from the middle Eocene Clarno Nut Beds. A complete skeleton is known from the middle Eocene (Bridgerian) of the Bridger Basin of Wyoming, and this was the basis for our reconstruction (Figure 8E), which is close to that of Charles Knight (for Osborn, 1910). More gracile reconstructions have been made by Bruce Horsfall (for W.B. Scott, 1913), Michael Long (Savage and Long, 1986), and William Scheele (1955). Although it had the appearance of a big cat, *Patriofelis ferox* lacked the precisely bladed carnassial teeth of modern carnivores and belonged to an extinct group of catlike carnivores (Oxyaenidae, Creodonta) (Carroll, 1988).

Protitanops curryi

A variety of limbs and skull fragments of a large brontothere have been found in the late Eocene (Duchesnean) Mammal Quarry of the upper Clarno Formation. Although referred to *Protitanops* (Lucas, 1992), there is doubt about this generic assignment (Mader, 1989). Our reconstruction (Figure 9F) is based on the generally similar *Protitanops curryi* Stock (1936) from the late Eocene (Chadronian) Titus Canyon Formation, east of Death Valley, California. Like *Telmatherium* (Figure 8B), *Protitanops* was a brontothere and a browser. It was much larger than *Telmatherium* and probably had a significant impact in destroying trees and other browse—like modern megaherbivores such as elephants and rhinos (Owen-Smith, 1988). The horns of this and geologically younger brontotheres were probably sexual display organs of male animals.

Plesiocolopirus hancocki

Several skull fragments and teeth of *Plesiocolopirus hancocki* (Radinsky) Schoch (1989) have been found in the Mammal Quarry of the upper Clarno Formation. Radinsky (1963) envisaged this species as intermediate between the earlier *Helaletes nanus* from the middle Eocene (Bridgerian) of Wyoming and the later *Protapirus* from the early Oligocene (Orellan and Whitneyan) Brule Formation of South Dakota (W.B. Scott, 1941)—which he regarded as the first true tapir. Our reconstruction (Figure 9C) was influenced by reconstructions of *Helaletes nanus* by Jay Matternes (see Dott and Batten, 1981) and Bruce Horsfall (for W.B. Scott, 1913) and by those of early Miocene *Miotapirus* by Graham Allen (for Dixon and others, 1992). The Clarno fossils have a large nasal incision and reduced nasal bones. These bones are not so modified as in living tapirs, so the proboscis of *P. hancocki* may not have been so large and flexible. Tapirs are forest browsers, and the teeth of *P. hancocki* are compatible with a similar diet.

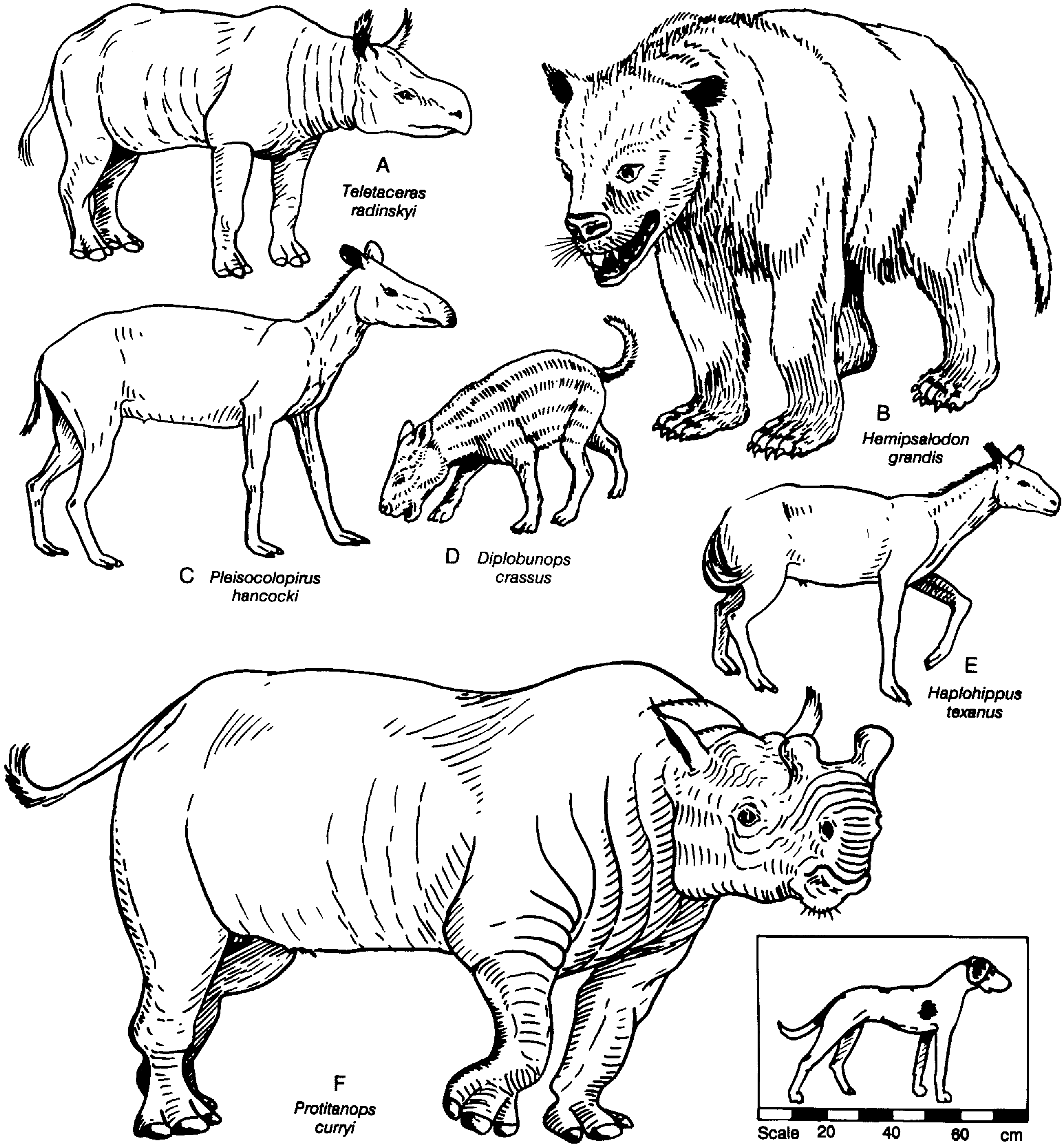

Figure 9. Reconstructions of late Eocene (Duchesnean) animals from the Mammal Quarry of the upper Clarno Formation at the OMSI Hancock Field Station, Oregon (scale from R.B. Horsfall for W.B. Scott, 1913; others original with inspiration from Stock, 1936; Russell, 1938; W.B. Scott, 1945; McGrew, 1953; Radinsky, 1963; Mellett, 1969; Savage and Long, 1986; Hanson, 1989; Dixon and others, 1992).

Teletaceras radinskyi

Teletaceras radinskyi Hanson (1989) was a small rhino, represented by skulls and a variety of other bones from the Mammal Quarry of the upper Clarno Formation. Hanson (1989) compared it with *Trigonias osborni* from the Late Eocene (Chadronian) Chadron Formation of South Dakota, a species reconstructed by Irving Biehn (for W.B. Scott, 1913) and Graham Allen (for Dixon and others, 1992). Compared with this geologically younger rhino, the Duchesnean *Teletaceras radinskyi* was a smaller and more gracile animal (Figure 9A). The Clarno rhino may have evolved from immigrant *Teletaceras* from Asia and represents an early true rhino (Rhinocerotidae). As with most rhinos, its teeth are those of a browser.

Haplohippus texanus

The primitive horse *Haplohippus texanus* McGrew, 1953, is represented by a variety of skull fragments and teeth from the Mammal Quarry of the upper Clarno Formation, as well as the late Eocene (Duchesnean) Porvenir local fauna of the Vieja Formation of Texas. The teeth of *Haplohippus texanus* ally it with primitive, forest-browsing horses such as *Orohippus* (Figure 8D), from which it differed by being larger, yet more gracile (Figure 9E). Another horse found in the Clarno Mammal Quarry, *Epihippus gracilis*, on the other hand, is even more gracile and cursorial and has more complex and larger molars, perhaps reflecting a preference for slightly more open habitats. *Haplohippus* was the last of the primitive hyracotheriine horses, but *Epihippus* was in the lineage giving rise to later three-toed horses (McGrew, 1953). Although horse evolution has been portrayed as a unidirectional trend, this and other examples indicate a luxuriant bush of evolutionary branches (MacFadden, 1992).

Diplobunops crassus

A skull of *Diplobunops* from the Mammal Quarry of the upper Clarno Formation is crushed and extensively cracked and may belong to a new species. Our reconstruction (Figure 9D) is based on better preserved material of *Diplobunops crassus* W.B. Scott (1945) from the late Eocene (Uintan) of the Uinta Basin, Utah, and on reconstructions of the allied genus *Agriochoerus* by Bruce Horsfall (for W.B. Scott, 1913). *Diplobunops* and *Agriochoerus* were part of a now-extinct group of creatures grouped into the family Agriochoeridae, which were primitive artiodactyls similar to the extinct but more familiar oreodons common in Oligocene and Miocene parts of the John Day Formation (Carroll, 1988). Their prominent canines and postcranial skeleton are superficially similar to those of dogs, although the tarsus is that of an artiodactyl. The cheek teeth, however, are low crowned and those of a browser.

Hemipsalodon grandis

The large carnivore *Hemipsalodon grandis* (Cope) Russell, 1938, is represented by a crushed but complete skull and lower jaws from the Mammal Quarry of the upper Clarno Formation (Mellett, 1969). This species is known from a variety of localities of late Eocene (Duchesnean and Chadronian) age from Saskatchewan in the north to near the Mexican border of Texas but remains very incompletely known. The bearlike reconstruction offered here (Figure 9B) is based partly on a facial reconstruction by Russell (1938) from Canadian specimens and on an associated astragalus of a plantigrade animal (Mellett, 1969). Although perhaps frugivorous to carnivorous like bears, *Hemipsalodon* was not closely related to them but rather belongs in an extinct group of creodont carnivores (Hyaenodontidae) (Carroll, 1988). *Sarkastodon* from the late Eocene of Mongolia is another bearlike creodont for which a reconstruction is available (by Graham Allen for Dixon and others, 1992).

Diceratherium annectens

Only molar fragments of the rhino *Diceratherium annectens* Marsh (1873) have been found in the late Oligocene (early Arikareean) Turtle Cove Member of the John Day Formation on Carroll Rim and the footslopes of Sutton Mountain, but excellent skulls and postcranial remains continue to be found at the same stratigraphic level in and around the Sheep Rock Unit of the John Day Fossil Beds near Dayville (Peterson, 1920). Our reconstruction (Figure 10A) is based on a hornless reconstruction by Bruce Horsfall (for W.B. Scott, 1913). This Oregon rhinoceros should not be confused with a Nebraskan Miocene rhino, formerly regarded as congeneric but now assigned to *Menoceras cooki* (Prothero and others, 1989) and reconstructed by Bruce Horsfall (for W.B. Scott, 1913). *Diceratherium annectens* had hypsodont teeth and was one of the earliest grazing mammals (Webb, 1977).

Miohippus quartus

The three-toed horse *Miohippus quartus* Osborn (1918) is represented only by fragmentary teeth in the late Oligocene (Arikareean) Turtle Cove Member of the John Day Formation in the Painted Hills area but by fine skulls in the same stratigraphic horizon to the east near Dayville. Other species of *Miohippus* represented by skulls and complete skeletons are known from the Oligocene (Orellan and Whitneyan) Brule Formation of South Dakota (Prothero and Shubin, 1989). These and a reconstruction by Charles Halgren and associates (for Simpson and Beck, 1963) were used to prepare our version (Figure 10B). *Miohippus* like the co-occurring *Mesohippus* was a three-toed horse with the low-crowned teeth of a browser. Nevertheless, both taxa, and *Miohippus* more than *Mesohippus*, have more complex, wider, and higher crowned teeth and more elongate limbs than geologically older forest horses such as *Haplohippus*, *Epihippus*, and *Orohippus*. These indicate adaptation to more open country. The distribution of fossil horses in paleosols of Oligocene age in South Dakota has suggested to MacFadden (1992), that *Mesohippus* preferred streamside woodlands, whereas *Miohippus* lived in more open, grassy vegetation of interfluves, an idea supported to a limited extent by our discovery of *Miohippus* in paleosols in Oregon (Bestland and Retallack, 1994b).

"Entelodon" calkinsi

The large, hoglike *"Entelodon" calkinsi* (Sinclair) Trox-

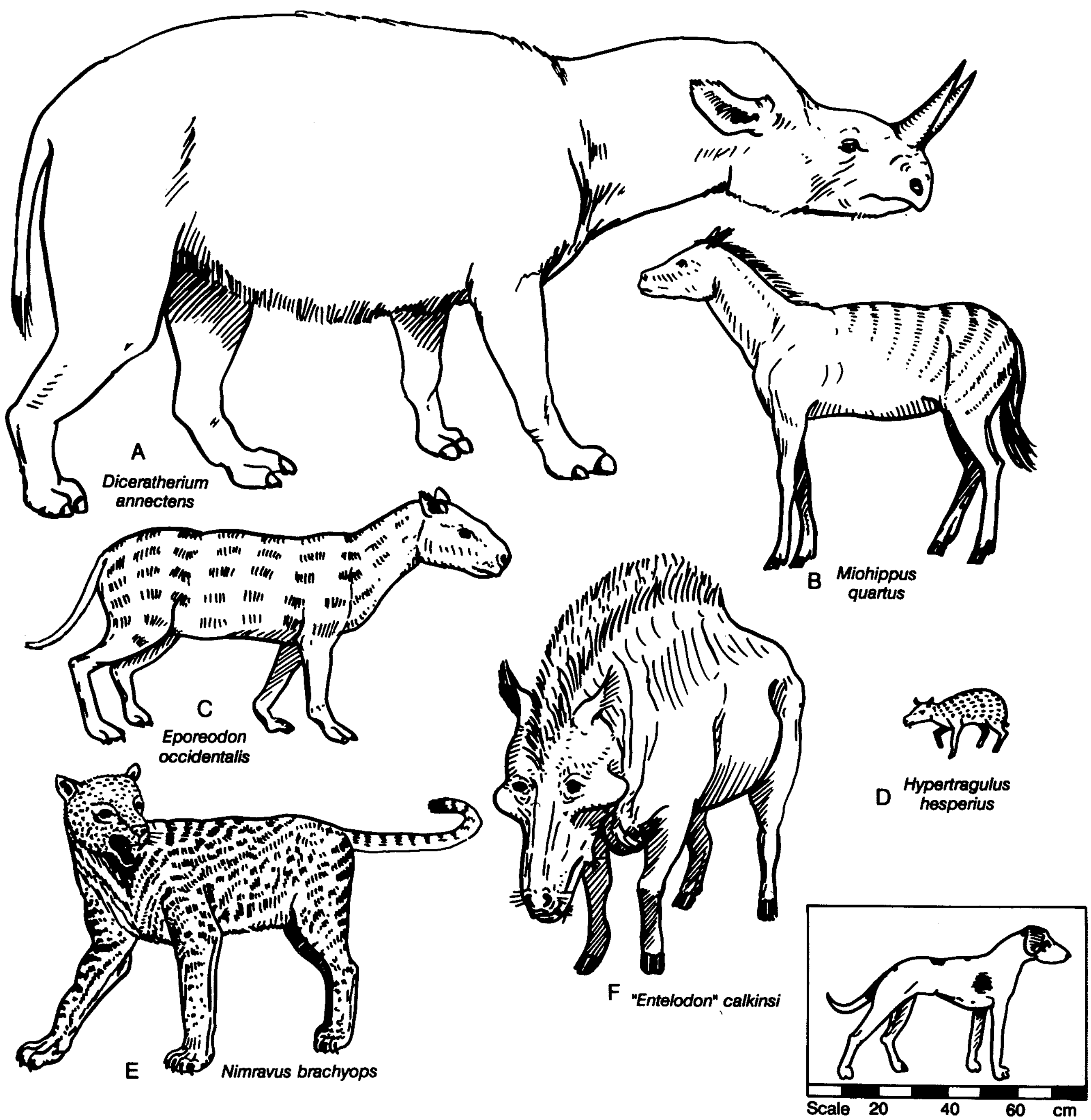

Figure 10. Reconstructions of fossil mammals known from the late Oligocene lower Turtle Cove Member of the John Day Formation in the Painted Hills area (A and scale by R.B. Horsfall for W.B. Scott, 1913; D from Dixon and others, 1992; others original with inspiration from Sinclair, 1905; Merriam, 1906; Osborn, 1918; Peterson, 1920; W.B. Scott, 1940; Simpson and Beck, 1963; Czerkas and Glut, 1983).

ell (1920) is represented by very fragmentary remains in the late Oligocene (Arikareean) Turtle Cove Member of the John Day Formation in the Painted Hills area but by a large and complete skull at comparable stratigraphic level in the Dayville area. *Entelodon* and allied genera belong to an extinct group (Entelodontidae), distinct from but allied to pigs (Carroll, 1988). Other species of entelodons have been widely reconstructed (W.B. Scott, 1913; Czerkas and Glut, 1982; Savage and Long, 1986; Dixon and others, 1992), but our version (Figure 10F) emphasizes the distinctive pattern of bony knobs on the jaw and cheeks of the skull described by Sinclair (1905). Entelodons are unique in many ways but were probably omnivore-scavengers (Joeckel, 1990).

Hypertragulus hesperius

The small mouse deer *Hypertragulus hesperius* Hay (1902) is one of the most abundant fossil mammals in the Turtle Cove Member of the John Day Formation but is represented mainly by fragmentary remains. Good skeletons of other species of *Hypertragulus* and the similar *Leptomeryx evansi* are known from the Brule Formation of South Dakota (W.B. Scott, 1940). These and the reconstructions of *L. evansi* by Charles Knight (for Osborn, 1910) have influenced our reconstruction of *Hypertragulus hesperius* (Figure 10D). *Hypertragulus* and *Leptomeryx* are placed in separate families (Hypertragulidae and Leptomerycidae) of extinct primitive ruminants allied to the living mouse deer (Tragulidae) of Southeast Asia and Africa. Like living mouse deer, the extinct ones were probably forest browsers.

Eporeodon occidentalis

Good skulls, including the holotype of *Eporeodon occidentalis* Marsh (1873), have been found in the late Oligocene (Arikareean) Turtle Cove Member of the John Day Formation in the Painted Hills area (Thorpe, 1921). The taxonomy of these abundant Oligocene mammals remains confused (Prothero and others, 1996). *Eporeodon occidentalis* was similar to though slightly more gracile and shorter limbed than the common *Merycoidodon culbertsoni* of the Badlands of South Dakota, which has been reconstructed by Bruce Horsfall (for W.B. Scott, 1913), Charles Knight (for Osborn, 1910), and Andrew Robinson (for Dixon and others, 1992). Both the local skeletons and these reconstructions influenced our reconstruction (Figure 10C). Oreodonts are a completely extinct group of endemic North American early artiodactyls (Merycoidontidae or Oreodontidae of Carroll, 1988). They have a sheeplike appearance but are unrelated to these domestic bovids. They have also been called ruminant hogs, but pigs were a separate lineage. And although part of the larger ruminant clade, living ruminants all evolved after oreodonts. Oreodonts have a limb structure that includes feet more like paws than hooves and teeth that are low crowned. They were probably browsing animals (Bakker, 1983).

Nimravus brachyops

Only a talonid allied to these early sabre-tooth cats (Nimravidae) has been found in the late Oligocene Turtle Cove Member of the John Day Formation in the Painted Hills area, but good skulls and limb bones of *Nimravus brachyops* (Cope) Cope (1879) are known from this stratigraphic level near Dayville to the west (Toohey, 1959). The reconstruction of Graham Allen (for Dixon and others, 1992) inspired our version (Figure 10E). Nimravidae were among the earliest of the true carnivores that began to replace archaic creodont carnivores in the late Eocene. The sabre-tooth specialization of these carnivores developed independently in several different lineages of cats, the last of which became extinct at the end of the Pleistocene. *Nimravus brachyops* did not have such exaggerated canines as many later sabre-tooth cats. Its limbs were elongate and toes reduced, more like a pursuit than ambush predator, though not so cursorial as the living cheetah (Merriam, 1906).

CONCLUSION

The John Day Fossil Beds National Monument conserves a fossil record of life and landscapes in central Oregon that continues to intrigue amateur and professional paleontologists. The quality of preservation and diversity of fossil plants and animals enables an unusually detailed view of Eocene and Oligocene life on land. Associated fossil soils allow paleoecological interpretations of the fossil assemblages, and abundant volcanic rocks allow their precise radiometric dating. With our reconstructions and supporting notes, we have attempted to introduce a few of the common extinct fossil plants and animals of central Oregon. In distilling 130 years of scientific study of these fossils we are keenly aware that much more remains to be done. John Day fossils will continue to amaze and inspire for years to come.

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John Day Fossil Beds National Monument has a home page on the Internet

Those interested in finding out more about the John Day Fossil Beds and ready to get on the Internet can find the home page of the John Day Fossil Beds National Monument under the address **http://www.nps.gov/joda**.

Without the final "joda" this address is for the National Park Service home page, which can lead you to many other sources of information on National Parks. □

BOOK REVIEWS

Fruits and Seeds of the Middle Eocene Nut Beds Flora, Clarno Formation, Oregon, by Steven R. Manchester. Ithaca, N.Y., Paleontological Research Institution, Palaeontographica Americana 58, August 24, 1994 , 205 p., including 70 plates, $65.00.

Reviewed by Ted Fremd, Paleontologist, John Day Fossil Beds National Monument, HCR 82 Box 126, Kimberly, OR 97848, e-mail Ted_Fremd@NPS.GOV

The predominantly volcaniclastic Clarno Formation, first recognized and described around the turn of the century (Merriam, 1901), covers a huge expanse of eastern Oregon. Manchester's excellent new monograph focuses on only a tiny portion of the record preserved in these strata. The Nut Beds flora is found in 44-million-year-old deposits at a minuscule site within the boundaries of what is now the Clarno Unit of John Day Fossil Beds National Monument. Ever since its discovery, this peculiar locality has puzzled and delighted many botanical workers. In 1942, a fossil enthusiast named Thomas Bones (who did not work with vertebrates) began diligently working these beds. By 1954, when the first monograph on the flora appeared (Scott, 1954), Bones had laboriously collected and painstakingly prepared microscopic specimens of fossil seeds and fruits from over 10 tons of material. Bones continued collecting for another 30 years, providing a classic example of the role "amateurs" can have in paleontology. He amassed significant collections housed today in major repositories where they are available for study, and he published a photographic atlas of his specimens (Bones, 1979).

Steve Manchester's new publication is an exhaustive and thorough summary of the Nut Bed fossil seeds and fruits. It is based on new examinations of over 20,000 specimens, most of them from Bones' collections. Manchester's effort is unique in the North American paleobotanical literature and has produced a huge success, particularly since the Nut Beds site has produced extraordinarily well preserved fruits, flowers, pollen, leaves, stems, roots, and other tissue systems in association.

A marvelously complex picture of a diverse (145 genera), paratropical flora emerges from Manchester's work. Vines or other climbing plants make up nearly half of the flora for which the growth habit can be deduced. A puzzling mix of palms, ferns, cycads, and numerous types of flowering plants is described (with only one herbaceous angiosperm, the banana Ensete, detailed in Manchester and Kress, 1993). For years, we have been comparing the Clarno rain forest to habitats such as those found in modern southeast Asia, but comparisons with modern forests fail to do justice to the diversity and degree of difference of the Clarno rain forest: it appears here much more bizarre than anybody had thought so far. If modern botanists could somehow walk through the Clarno jungle, they would not just see alien species—they would be unable to assign over half of the plants to any of the modern families!

A small but equally odd suite of vertebrates is also known from the Nut Beds, including crocodilians, primitive horses, and brontotheres, some of which undoubtedly feasted on the fruits and helped to disperse the plants.

Professionals and amateurs alike will be delighted with the great number and quality of the photographic plates in Manchester's book. I counted 1,155 clear, crisp images of 170 species with excellent descriptions, including whole-rock specimens, acetate peels, stereopairs, and beautiful scanning-electron microscopy. Incidentally, these photographs would be very useful on a CD-ROM linked to the text descriptions and illustrations, as several publishers are finding. The bulk of the text (90 of 120 pages) is concerned with descriptions of the taxa, including dozens of new species and/or combinations, following standard systematic procedure. The descriptions are accompanied by discussions, clear text figures, and well-designed tables that do an excellent job of clarifying synonymies.

Among the figured specimens are some that may correspond to insect reproductive structures rather than plants. Plate 66, for example, includes illustrations of "seeds" that I had assumed were brood chambers of one or more species of burrowing hymenopteran that are also found in younger John Day Basin strata. In recognizing the possibility of incorrect identification, Manchester decided that, "Rather than exclude taxa that could possibly be construed as insect eggs, I believe it is useful to document all of the structures because of the possible importance for biostratigraphy and/or future insect work" (p. 18). Still, the consequence is somewhat odd: One may have to consult botanical descriptions of micropyles, seed coats, and endosperm cavities for what may be entomological features.

Incidentally, paleobotanists are not the first organisms tempted into thinking that some of the little shapes we find today in Clarno muds are plant seeds. Modern species of "stick insects," of which the oldest known fossil eggs are found in the Nut Beds (Sellick, 1994), have evolved a complex mimicry: They succeed in fooling some ants into thinking the stick insect eggs are a type of plant seed. The ants carry these "seeds" into their nests, unwittingly assisting the reproductive efforts of the stick insects—as presumably their Eocene counterparts did.

Not much can be found that detracts from the excellence of Manchester's work. Among some minor flaws is the erroneous location in text figure 3 of the Hancock Quarry, placed in an outcrop rather far from the actual site. The pages devoted to the geology contain several antiquated interpretations of what is admittedly a puzzling stratigraphic sequence, and they are only partially corrected by "Notes added in proof." For example, instead of the earlier identification of the Nut Beds as "predating an andesitic plug" (p. 9), it is now clear that the Nut Beds actually are high in a section of lahars that accumulated on top of the plug (which is actually dacite) (Bestland and others, 1994). Manchester dismisses the long-standing "lake delta" hypothesis and rightly points out that the evidence is more consistent with a flood/slurry deposit associated with a lahar.

Unfortunately, the binding is pathetically inadequate for a book of this caliber. Since it will often serve as a reference, users will have to reinforce the binding to guard against losing individual pages.

Fruits and Seeds of the Middle Eocene Nut Beds Flora is a major contribution to paleobotany and an indispensable reference tool that belongs on the shelves of every paleobotanist and worker who deals with any aspect of the terrestrial Tertiary.

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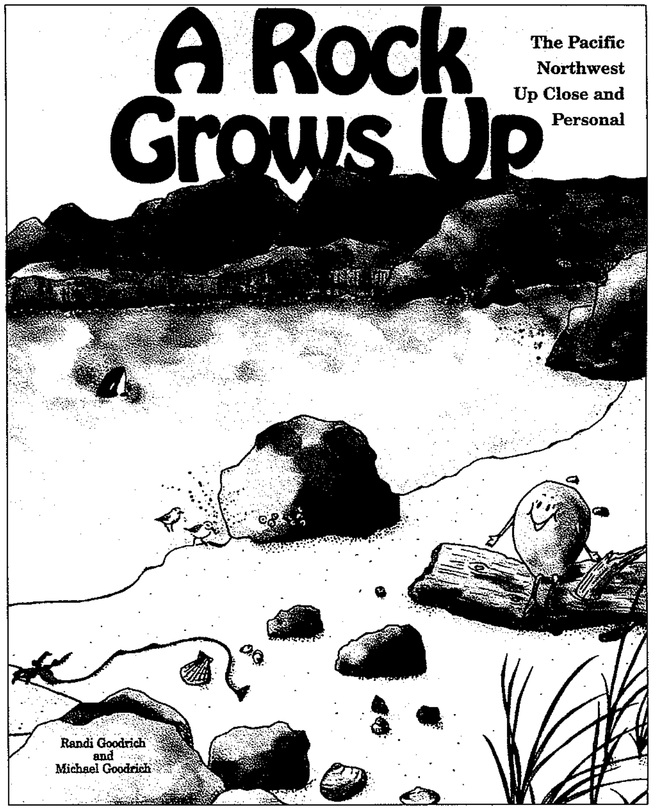
A Rock Grows Up, by R. and M. Goodrich. Lake Oswego, Oreg., GeoQuest Publishing, 56 p., $9.95.

A Rock Grows Up is the title of a children's book, created by Lake Oswego high school teacher Michael Goodrich and his wife Randi and delightfully illustrated by Michele Han, honor student at Lake Oswego High School. The book introduces earth science concepts in such a way that they become appealing and easily comprehensible to children at the elementary school level.

Following the story of Barry Basalt, the rock that grows up, young readers of the large-print book meet a dozen characters—family members and neighbors—that represent rocks and rock-forming minerals, such as Larry Gneiss and Annie Augite. They all participate in the great geologic cycle of rock formation and decomposition that starts in the asthenosphere below a sea-floor spreading ridge and leads through plate subduction, volcanism, weathering, sedimentation, and metamorphosis—from formlessness into form and back.

The whimsical pictures of the characters in the story are accompanied by schematic block diagrams that illustrate the geologic processes as they occur in the earth from the Juan de Fuca Plate to the Cascade Range—once even to Picture Gorge. In this sense, the book addresses children of Oregon and, to a lesser extent, the Pacific Northwest, conveying the framework of basic geology these children can experience at home.



Cover of *A Rock Grows Up*

The about fifty pages of the book include also a glossary of geologic terms and an index, also a list of significant technical books that introduce the teacher to the geology of the Pacific Northwest and to the major processes touched upon in the story of Barry Basalt. A bit of caution is advised in following the pronunciation aids given throughout the text and the glossary. A teacher may want to try them out before introducing them to children of the Northwest.

A Rock Grows Up is conceived as a teaching tool and thus accompanied by more teaching aids: a curriculum guide for student activities in lab exercises, coloring, and creative writing and with more materials for the use of the teacher ($7.95). The authors also offer a kit containing tagged samples of the rocks and minerals of the story ($14.95).

The book and accompanying materials are available from the publishers, GeoQuest Publishing, P.O. Box 1665, Lake Oswego, OR 97035, phone (503) 635-4420; or from the Nature of the Northwest Information Center on the ground floor of the State Office Building in Portland (see address on last page of this issue). □

Offshore volcanic activity reported

The Nature of the Northwest Information Center has received numerous inquiries about volcanic activity off the Oregon coast. Internet users can find up-to-date information on this subject in the U.S. Department of Commerce NOAA/PMEL/VENTS Program under the address **http://www.pmel.noaa.gov/vents/eruption.html**. □

Oil and gas exploration and development in Oregon, 1995

by Dan E. Wermiel, Petroleum Geologist, Oregon Department of Geology and Mineral Industries

ABSTRACT

Oil and gas leasing activity was about the same during 1995 as it was in 1994. Four U.S. Bureau of Land Management (BLM) lease sales were held, and offers were received on three tracts comprising 8,250 acres located in Jefferson County, Oregon. A total of 11,760 federal acres were under lease at year's end. The State of Oregon conducted no lease auctions during the year. A total of 16 State of Oregon tracts were under lease at year's end and consisted of 25,520 acres, which is the same as 1994. Columbia County held no lease sales during 1995.

During 1995, no exploratory wells were drilled in Oregon, primarily due to the fact that the operator of Mist Gas Field, Nahama and Weagant Energy Company, had filed for bankruptcy during 1994. The field was put for sale, and Enerfin Resources was the successful bidder and will become operator of the majority of the wells at the field upon finalization of the ownership transfer. Oregon Natural Gas Development Company acquired ownership of 10 wells and certain leases at Mist Gas Field.

At the Mist Gas Field, 18 wells were productive during 1995. A total of 2.5 Btu of gas was produced with a total value of $1.8 million during the year. This is a significant decline from the 4.2 Bcf of gas with a total value of $6.4 million produced during 1994. Reasons for the decline in production during 1995 include the normal decline in the wells at the field; the record low of prices paid for gas, which discouraged exploration and production activities; and the decommissioning of the Nitrogen Rejection Unit during 1995, which caused several low-Btu wells to be suspended.

Final reports on the DOGAMI five-year study of the oil, gas and coal resource potential of the Tyee Basin should be published during 1996. No changes to statutes and administrative rules were made during the year.

LEASING ACTIVITY

There was little oil and gas leasing activity in Oregon during 1995. This is a continuation of a generally declining trend in leasing activity that began during the late 1980s. Activity included four public sales by the BLM at which a total of three offers were received for oil and gas leases on lands in Jefferson County. Robert F. Harrison, Seattle, Washington, applied for 8,250 acres during December 1995. He and other individuals have held leases on a block of federal land comprising about 11,680 acres in this general area since 1977. This acreage, plus an 80-acre parcel located in Columbia County in the vicinity of Mist Gas Field, are the only federal lands presently under lease in Oregon. Total rental income to the BLM was $11,760 during 1995. Applications were pending on 13,103 federal acres at the end of 1995, which is a decrease from applications pending on 39,942 acres at the end of 1994 because the majority of such offers were withdrawn during the year.

The State of Oregon held no lease sales during 1995, and no State oil and gas leases were issued during the year. With no changes during the year, a total of 16 State of Oregon tracts comprising a total of 25,250 acres were under lease at year's end, and total rental income was $25,250—the same as in 1994.

Columbia County held no lease sales during 1995.

DRILLING

For the second consecutive year, no exploratory oil and gas wells were drilled in Oregon. Before this, exploratory wells for oil and gas had been drilled in Oregon each year from 1974 until 1993. The lack of drilling during 1995 is largely attributed to the fact that Nahama and Weagant Energy Company, the operator of Mist Gas Field, had filed for bankruptcy during 1994. A court-appointed trustee was assigned to sell the assets of Nahama and Weagant Energy Company, including the Mist Gas Field. During 1995, Enerfin Resources of Houston, Texas, was the successful bidder for the Mist Gas Field and will become the operator of the field. It was reported that negotiations were completed during December 1995, which transferred ownership of ten wells and certain leases to Oregon Natural Gas Development Company (ONGD) of Portland, Oregon. ONGD is now the operator of the following wells: CC 13–34, CC 43–33–75, CC 23–22, CC 43–22, CC 31–27–65, CC 14–23, CC 44–27–65, CC 31–34–65, CC 21–35–65, and LF 12B–35–65. All other wells at Mist Gas Field are operated by Nahama and Weagant Energy pending finalization of the transfer of ownership to Enerfin Resources.

During 1995, DOGAMI did not issue any permits to drill, while four incomplete applications were withdrawn. Permit activity is listed in Table 1.

Table 1. Oil and gas permit activity in Oregon 1995

Permit number	Operator, well, API number	Location	Permit activity
440	Norwestco, Inc. 1–29 36–069–00009	SW¼ sec. 29 T. 9 S., R. 23 E. Wheeler County	Incomplete application, withdrawn.
485	Carbon Energy Menasha 28–1 36–001–00025	SW¼ sec. 28 T. 26 S., R. 13 W. Coos County	Incomplete application, withdrawn.
498	Carbon Energy Menasha 1–16 36–011–00028	SE¼ sec. 16 T. 26 S., R. 13 W. Coos County	Incomplete application, withdrawn.
499	Carbon Energy Menasha 1–16 36–011–00028	SE¼ sec. 32 T. 26 S., R. 13 W. Coos County	Incomplete application, withdrawn.

PRODUCTION

Despite the bankruptcy of Nahama and Weagant Energy Company, the Mist Gas Field operated normally during the year. The field had a total of 18 wells that were productive during the year, which is a decline from 21 wells productive during 1994. The wells produced 2.5 Bcf of gas, a significant decrease from the 4.2 Bcf of gas produced during 1994. This decrease was largely the result of the three factors. The first is the normal decline of the existing wells at the field. The second factor is the record low price received for gas at the Mist Gas Field since it was discovered during 1979, which discouraged exploration and production at the field. The gas prices paid during 1995 ranged from 4 cents to 11 cents per therm during the year until December, when they increased to 22 cents per therm for the month. During 1994, gas prices ranged from 11 to 23 cents per therm. The final reason for the production decline during 1995 was the decommissioning of the Nitrogen Rejection Unit (NRU) that was installed during 1994. The NRU enabled three low-Btu wells at Mist Gas Field to go on production by separating the methane gas from noncombustible nitrogen gas. However, due to the cost to run the NRU, decline in production of the low-Btu wells, and other factors, the NRU was decommissioned during the year and the three low-Btu wells were shut in. As a result of the low production volume and low gas prices during 1995, the total value of the gas produced at Mist Gas Field was $1.8 million, a significant decline from the $6.4 million during 1994. Cumulatively, the Mist Gas Field has produced about 56.5 Bcf of gas with a total value of $112.8 million since it was discovered in 1979.

GAS STORAGE

The Mist Natural Gas Storage Project remained fully operational during 1995. The gas storage project has nine injection-withdrawal service wells, five in the Bruer Pool and four in the Flora Pool, and thirteen observation-monitor service wells. The two pools have a combined storage capacity of 10 Bcf of gas. This allows for the cycling of about 6 Bcf of gas in the reservoirs at pressures between approximately 400 and 1,000 psi and will provide for an annual delivery of 1 million therms of gas per day for 100 days. During 1995, about 4,469,288 cubic feet of gas was injected, and 3,566,865 cubic feet was withdrawn at the Mist Storage Project. Plans are underway by ONGD to develop additional storage pools at the Mist Gas Field during 1996.

OTHER ACTIVITIES

DOGAMI has completed a five-year study of the oil, gas, and coal resource potential of the Tyee Basin located in Douglas and Coos Counties in the southern Coast Range. The study, which was funded by landowners in the study area and by county, state, and federal agencies in a public-private partnership, is an investigation of source rock, stratigraphy, and structural framework for those character-

(Continued on page 74)

ABSTRACTS OF PAPERS

The following abstract is of a paper given at an international conference in May 1995 at the University of Washington. The conference, titled "Tsunami deposits—geologic warnings of future inundation," was sponsored by the Quaternary Research Center, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey. Among the 80 registered participants were scientists from Canada, Germany, Japan, Norway, the Philippines, the United Kingdom, and the United States.

A paleohydraulic reconstruction of 300-year old tsunami deposits at Willapa Bay, Washington State, by Mary Ann Rinehart, GeoEngineers, Inc., Redmond, Wash.; and Joanne Bourgeois, Department of Geological Sciences, University of Washington

Sand sheets about 300 years old along the southern Washington coast can be explained by a tsunami generated at the Cascadia Subduction Zone but not by storm setup or seiching. These sand sheets, preserved in many parts of the interiors of Willapa Bay and Grays Harbor estuaries, overlie a buried peaty soil indicating abrupt subsidence. They are composed of one to five horizontal laminae of sandy silt or silty sand, alternating with laminae of mud. The character and sedimentology of the deposits indicate that (1) the depositional mechanism was a single, landward-directed event comprising multiple pulses; (2) each lamina was deposited rapidly from a high concentration of suspended sediment; (3) velocities and boundary shear stresses generated during each pulse were high enough to entrain and suspend sufficient volumes of sand and silt into the overbank part of the flow from tidal-channel floors; (4) overbank velocities were sufficient to transport sand up to about 200 m across marsh surfaces; and (5) a period of quiet water followed deposition of each sandy lamina.

As a test of the tsunami hypothesis we used a simple sediment-transport model to reconstruct the conditions necessary to deposit sandy laminae on marshes along the Niawiakum River, an arm of Willapa Bay. We assumed (conservatively) steady-flow conditions and uniform distribution of sand and silt throughout the overbank part of the water column. Discharge and suspended-sediment concentrations were reconstructed with a simple advection model applied to the lateral distribution of grain sizes in the basal sandy lamina. We then constrained the rate of lamina deposition, overbank flow depth, and pulse period by matching the component concentrations (estimated from the overbank trajectory model) to concentrations generated within the channel as calculated from the Rouse equation. The results of the reconstruction indicate overbank flow depths of 1–2 m, pulse periods of 18–30 min, and in-channel velocities of 340–400 cm/s.

A tsunami wave train provides the best fit to results of the reconstruction, based on wave period, number of pulses, water velocity, and distribution of the sand sheet around

Willapa Bay and Grays Harbor. The calculated wave periods are consistent with known tsunami periods and inconsistent with the calculated seiche period for Willapa Bay (1.5–2 hrs.)

The number of pulses is also improbable for a seiche, as it is unlikely the bay could seiche the required number of times, given its shallow, irregular bathymetry. Storms are unlikely to have produced the calculated flow velocities, maximum combined storm/tidal current velocities at the entrance of Willapa Bay are not known to exceed 250–300 cm/sec, and channel-flow velocities of that magnitude would not be maintained in protected tidal channels such as the Niawiakum River. Finally, the regional extent of the deposit, as well as its characteristics and local variation, can be explained by tsunami wave behavior. □

(Continued from page 73)

istics that are needed to generate and trap oil and gas. The final data, reports, and maps are expected to be published by DOGAMI during 1996. A series of maps and preliminary reports that present a revised understanding of the geologic framework of the Tyee Basin have already been published. Contact DOGAMI for a complete publication list including those for the Tyee Basin study.

The Northwest Energy Association, formerly the Northwest Petroleum Association, remained active for the year and has over 100 members. At its regular monthly meetings, speakers give talks generally related to energy matters in the Pacific Northwest. The 1995 symposium was held at Astoria, Oregon, on underground natural gas storage and energy-related matters of interest in the region. Plans are now underway for the 1996 symposium, which will be held in the Seattle, Washington, area. For information, contact the NWEA, P.O. Box 6679, Portland, OR 97228.

During 1996, no legislative or rule changes were made to DOGAMI statutes and administrative rules related to oil and gas drilling exploration activities. Copies of current statues and administrative rules can be obtained from DOGAMI. □

In memoriam: Barbara Jacob, Cliff Speaker

The Oregon Department of Geology and Mineral Industries (DOGAMI) mourns the death of two former staff members, both retired.

Barbara Ann Jacob died March 4, 1996, at age 75, in Portland. She was a native of Tacoma and lived most of her life in Portland. She was a secretary for DOGAMI for 15 years until her retirement in 1986 and specialized in the regulatory work of the oil and gas section. Barbara leaves a son, R. Larry, in Vancouver, Washington; a daughter, Carolyn Harmon, in Olympia; a sister, Gloria Kingsley, in Milwaukie; a brother, Dee Swayze, in Santa Clara, California; and three grandchildren.

Clifford Drake Speaker died March 6, 1996, at age 82. He was born in Parkrose and lived in Vancouver, Washington, from 1983 until his death. He was an accountant for Publishers Paper Company and then worked as business manager for DOGAMI from 1970 until his retirement in 1978. His surviving family includes his wife, Rachel C.; a daughter, Marylou S. Churchill, in Boston; sons Paul, in Upland, California, and Michael, in Portland; stepsons Roger Cole, in Vancouver, and Douglas Cole, in Bellingham, Washington; and three grandchildren. □

DOGAMI PUBLICATIONS

Released May 1, 1996:

Tsunami Hazard Map of the Siletz Bay Area, Lincoln County, Oregon, by G.R. Priest, M. Qi, A.M. Baptista, C.D. Peterson, and M.E. Darienzo. Geological Map Series GMS–99, $6.

This map of the area between Lincoln City and Gleneden Beach outlines five tsunami hazard zones for elevations between sea level and about 100 ft (30 m). The map was produced by the joint efforts of scientists from DOGAMI, the Oregon Graduate Institute of Science and Technology, and Portland State University and is intended primarily for planning for evacuation in the event of a tsunami.

The tsunami hazard map shows a black-and-white airphoto image of the coastal zone with elevation contours superimposed. The scale of 1:12,000 (1 inch = 1,000 feet) allows identification of streets and medium-sized structures. Three different types of red lines mark tsunami runup elevations that serve to separate risk zones: extreme risk, high risk, moderate risk, and low risk; the fifth category, negligible risk, is identified as those lands above 100 feet (30 m) in elevation. The map also identifies drill sites where cores revealed buried soils and, in some cases, tsunami sand layers from prehistoric events.

For evacuation planning, the new tsunami map should be used in conjunction with the relative earthquake hazard maps of the area published earlier by DOGAMI as Geological Map Series map GMS–93 ($20).

Explanation of Mapping Methods and Use of the Tsunami Hazard Map of the Siletz Bay Area, Lincoln County, Oregon, edited by G.R. Priest. DOGAMI Open-File Report O–95–05, 69 p., $6.

This 69-page paper contains detailed discussions of the map mentioned above and of its use. It also describes the development of the methods used to produce the map and the geologic evidence of prehistoric earthquakes and tsunamis on the coast.

These DOGAMI publications are now available over the counter, by mail, FAX, or phone from the Nature of the Northwest Information Center and the DOGAMI field offices in Baker City and Grants Pass (addresses on p. 50). Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment. □

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