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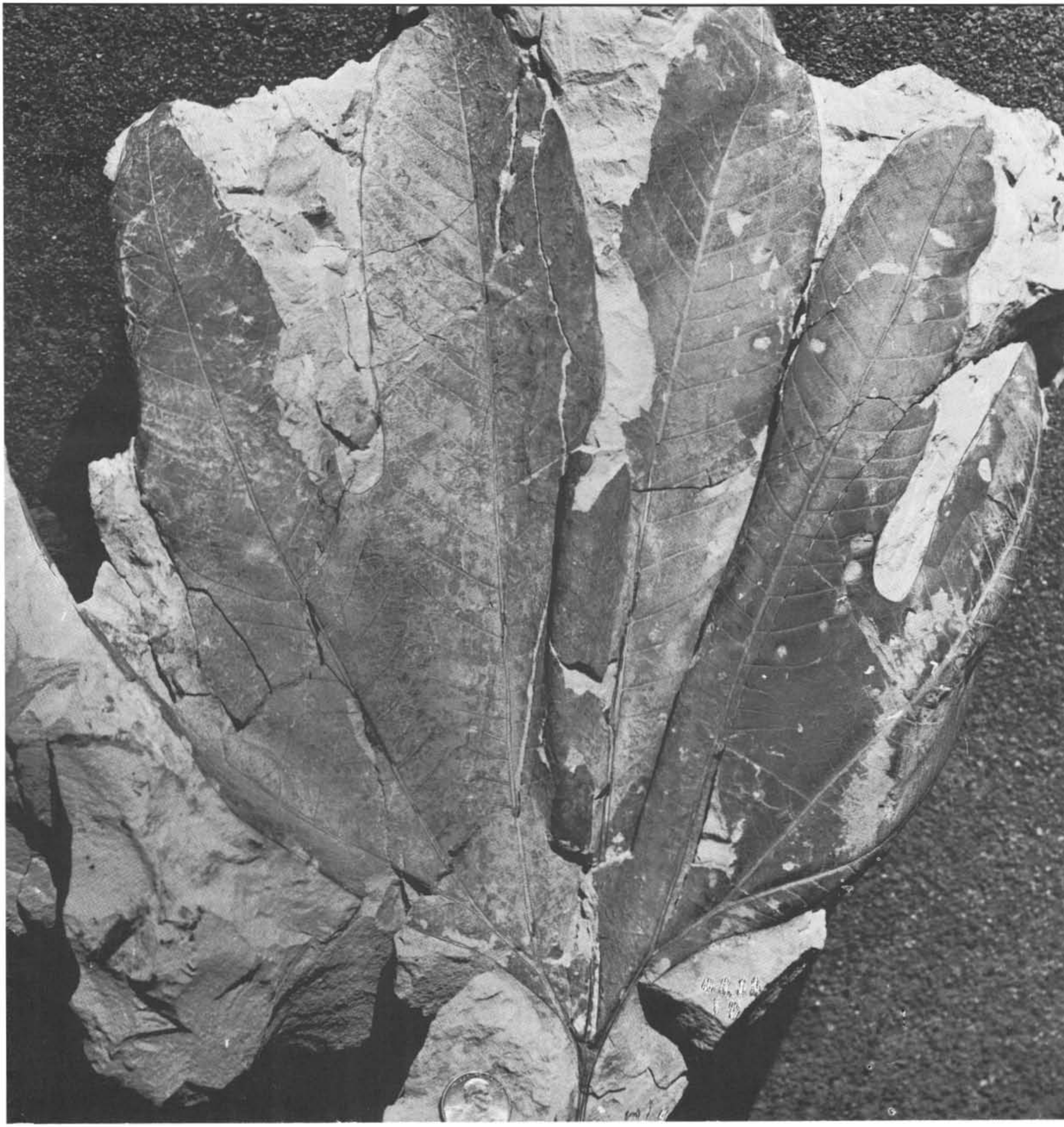

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Open-file reports assess geothermal resources of areas in central and eastern Oregon

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

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

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

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

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

COVER PHOTO

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

CONTENTS

Fossil plants of the Eocene Clarno Nut Beds

by Steven R. Manchester, Paleobotany Laboratory, Indiana University, Bloomington, Indiana 47405, and Earth Science Laboratory, Oregon Museum of Science and Industry, 4015 S.W. Canyon Road, Portland, Oregon 97221

INTRODUCTION

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

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

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

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

GEOLOGY AND AGE

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

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

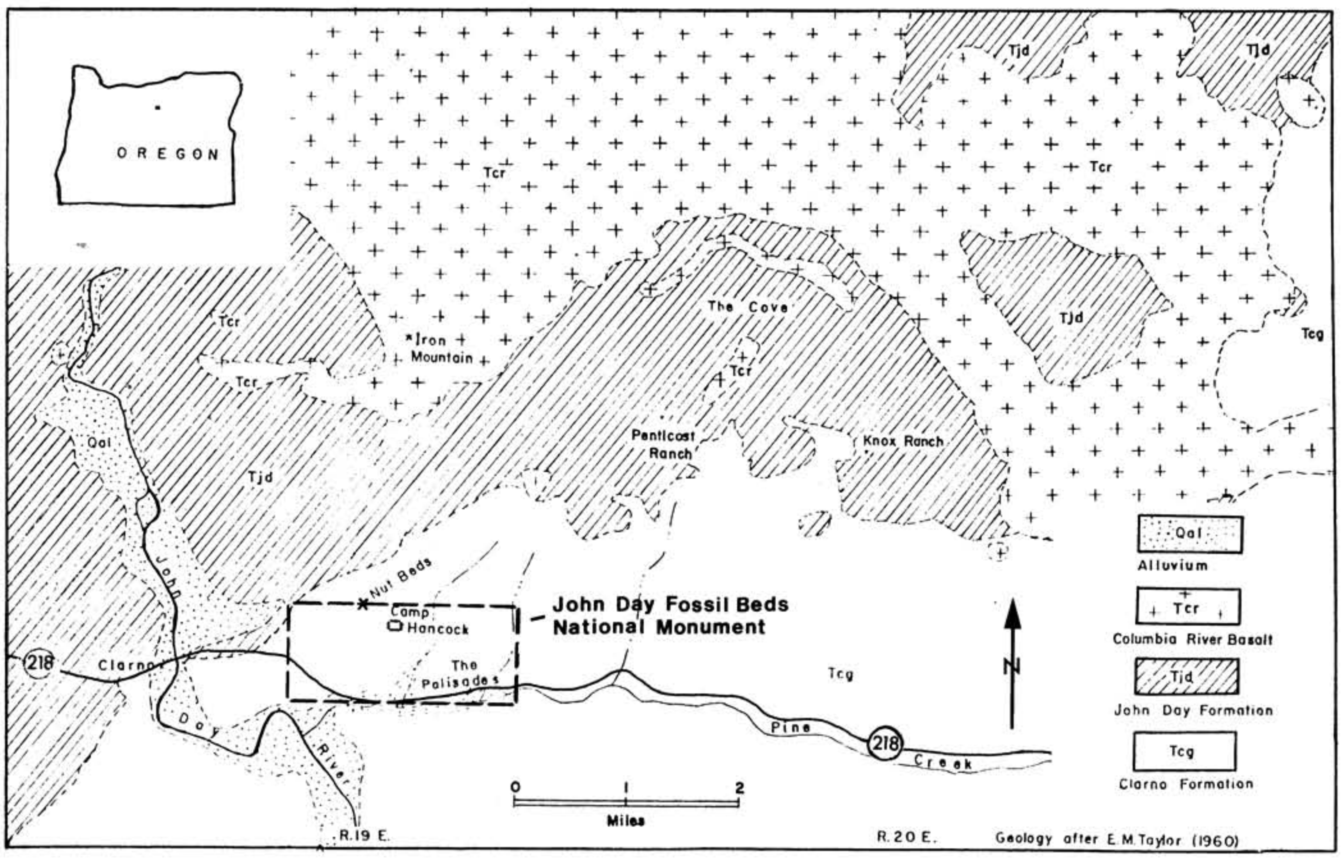


Figure 2. Northwesterly view of the Nut Beds. The deposit crops out in the faces labeled 1 through 4.

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

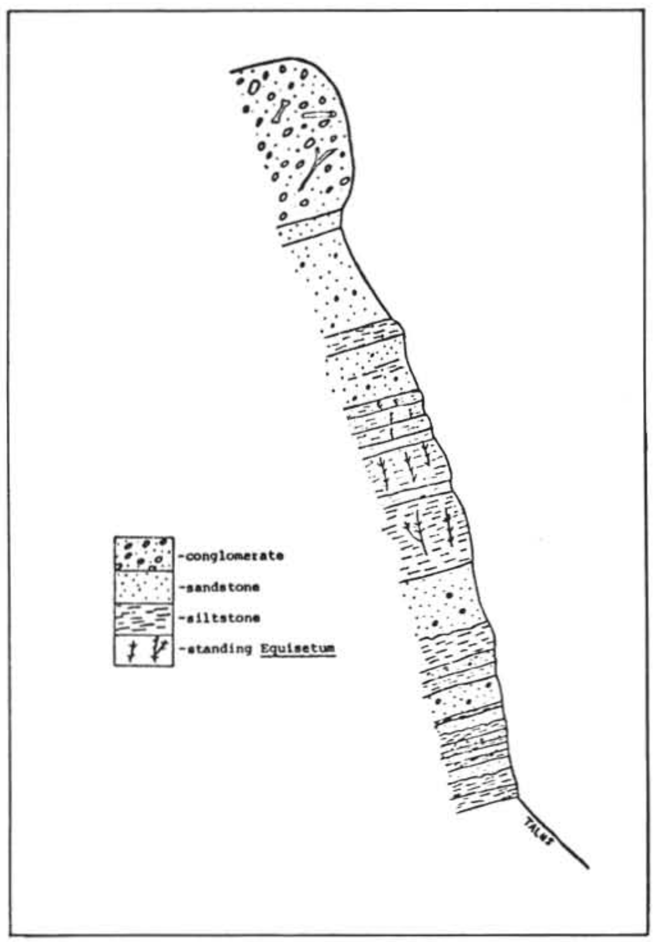


Figure 4. Generalized stratigraphic column for the Nut Beds based on measurements from Face 3. Section measures 10 m in thickness.

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

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

FOSSIL LEAVES

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

FLORAL COMPOSITION

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

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

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

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

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

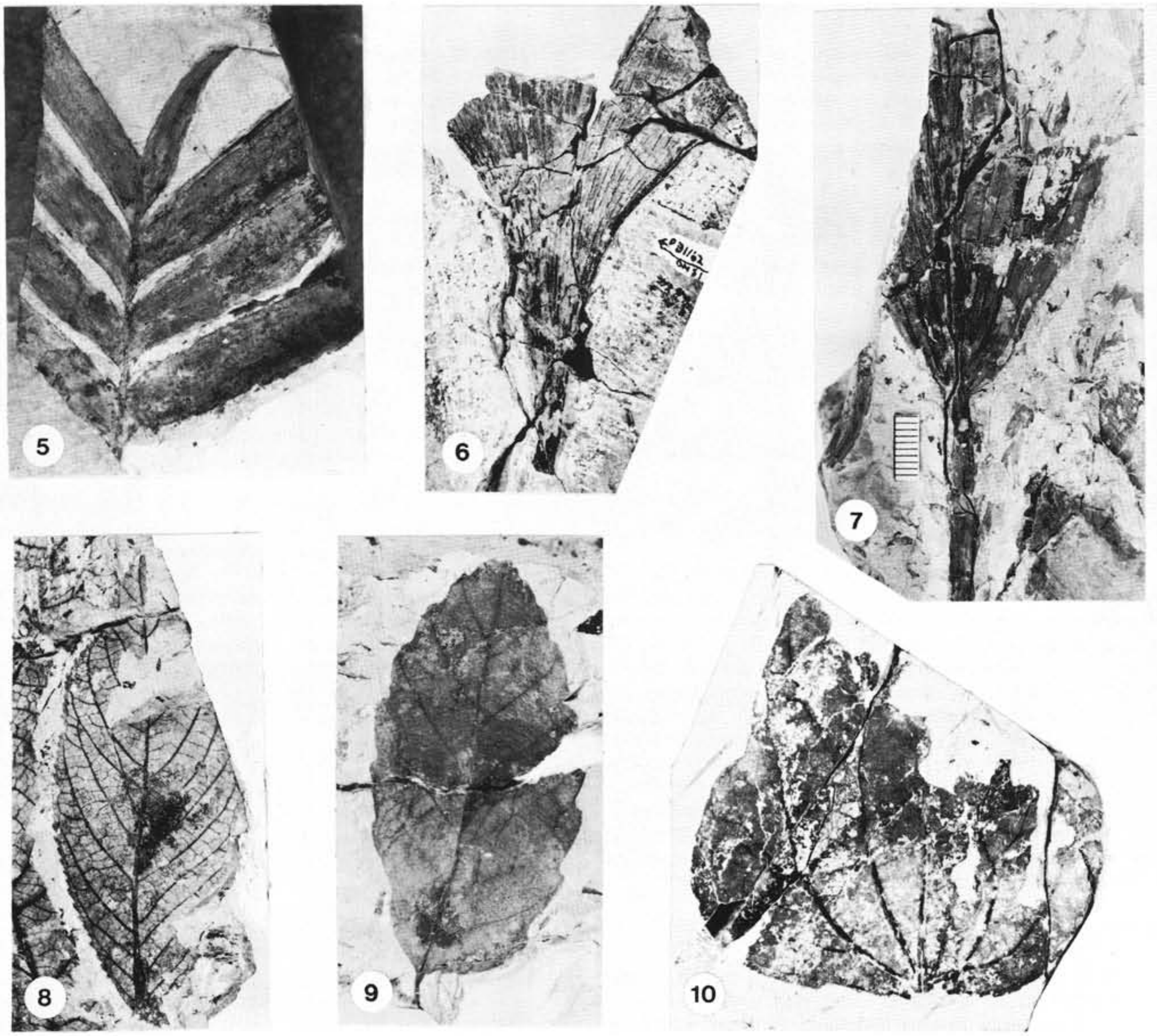
New identifications apply to two of the taxa figured by Bones (1979). Fruiting heads formerly thought to be *Altingia* (Bones, 1979, plate 2, Figure 5) have been shown to be *Platanus* (Manchester and Dilcher, 1980). Specimens figured as unidentified endocarps by Bones (1979, plate 6, Figures 1 and 2)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

ENVIRONMENTAL CONSIDERATIONS

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

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

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



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

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

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

EVOLUTIONARY IMPLICATIONS

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

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

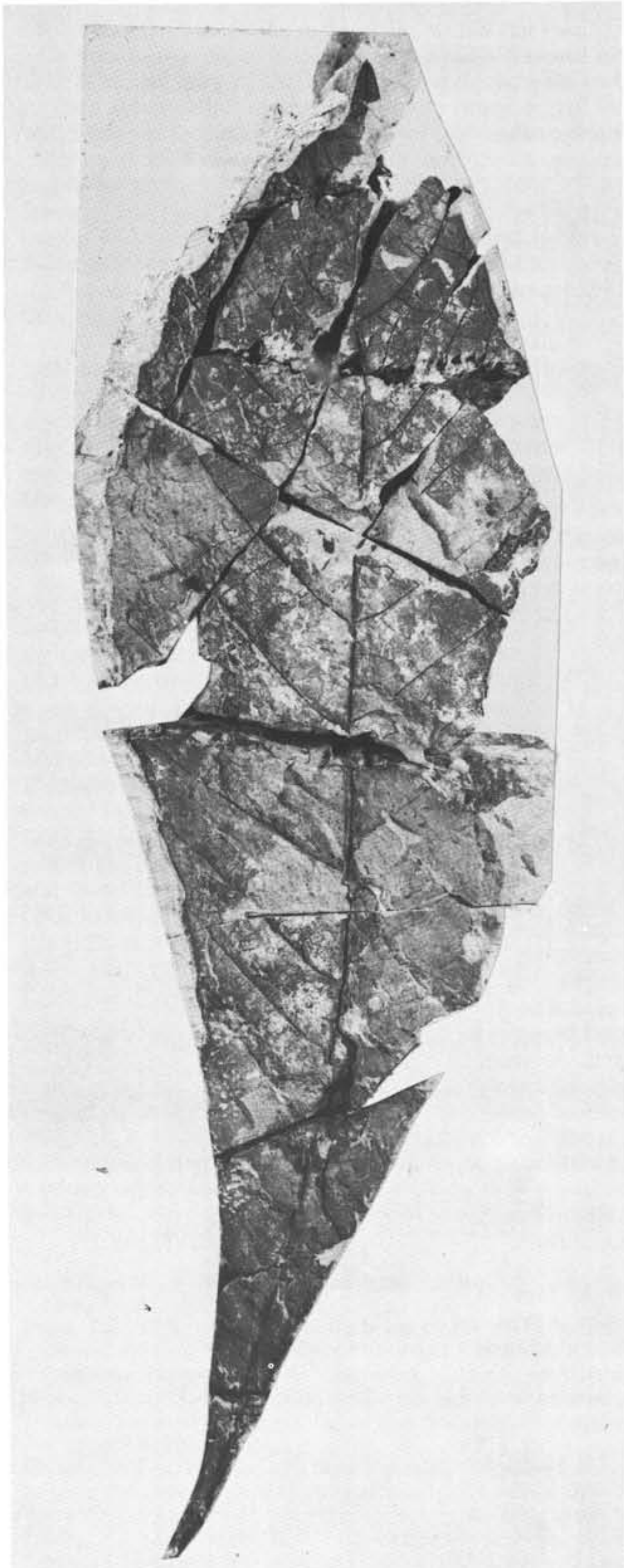


Figure 11. Meliosma. *A common leaf type in the Clarno Formation. Today this genus occurs in tropical Asia and Central and South America. Natural size.*

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

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

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

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

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

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

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

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

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

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

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

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

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

ACKNOWLEDGMENTS

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

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Note to the reader:

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

Nickel: The strategic metal Oregon supplies to the rest of the United States

by Jerry J. Gray, Economic Geologist, Oregon Department of Geology and Mineral Industries

What strategic metal does Oregon supply to the rest of the United States?

Nickel. Oregon has the only producing nickel mine in the United States.

How much of the nation's demand for nickel does Oregon supply?

Oregon's annual production of contained nickel in ferronickel (a combination of 50 percent iron and 50 percent nickel) ranges from 14,000 to 16,000 tons, which is 6 to 10 percent of the nation's demand for nickel. Scrap accounts for another 20 to 30 percent of the annual consumption; the rest is imported.

Why is nickel called a strategic metal?

Nickel is vital to the iron and steel industry. Nickel's greatest value is in alloys with other elements, where it adds strength and corrosion resistance to steel over a wide range of temperatures. Without nickel, our modern-day society would not be possible.

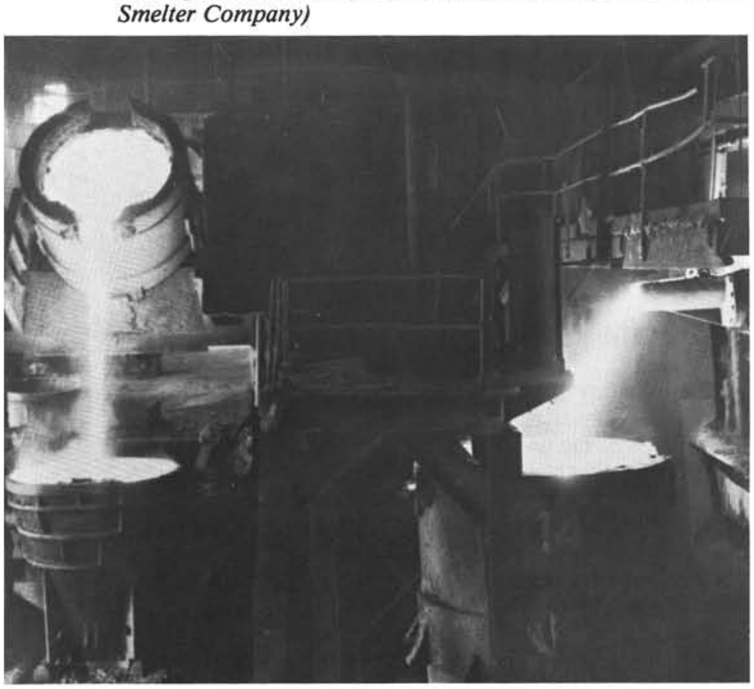
Where in Oregon is nickel ore mined and smelted?

The ore body being mined is on top of Nickel Mountain. The smelter is at the foot of the mountain. Nickel Mountain is located 4 mi west of the town of Riddle in southwestern Douglas County in southwestern Oregon.

How did the mine and smelter come into being?

In early 1953, two subsidiaries of the M. A. Hanna Company signed a Federal contract to build a nickel smelter and to develop the deposit of nickel ore at Nickel Mountain for the national stockpile. The firm was to furnish 95 to 125 million lbs of contained nickel in ferronickel at a price of 79.39¢ per lb for the first 5 million lbs and 60.5¢ per lb thereafter. In later years, when the Federal government sold the ferronickel from its stockpile, it realized over $2.00 per lb.

Left side of photo shows slag being poured from reaction ladle into slag pot. Right side shows molten ore being poured from melting furnace into reaction ladle for continuous melting batch reaction process. (Photo courtesy Hanna Nickel Smelter Company)



Who operates the mine and smelter?

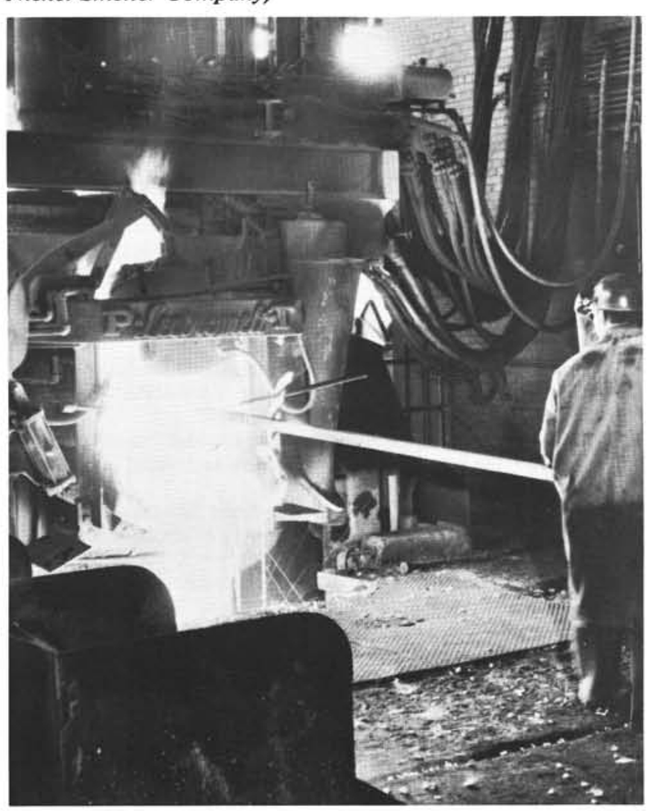
The Hanna Mining Company and Hanna Nickel Smelting Company began production of ferronickel in July 1954. This ferronickel was the first to be produced in the United States from domestic ores. The companies have operated on an around-the-clock schedule since that time, providing steady, year-round work for approximately 600 employees.

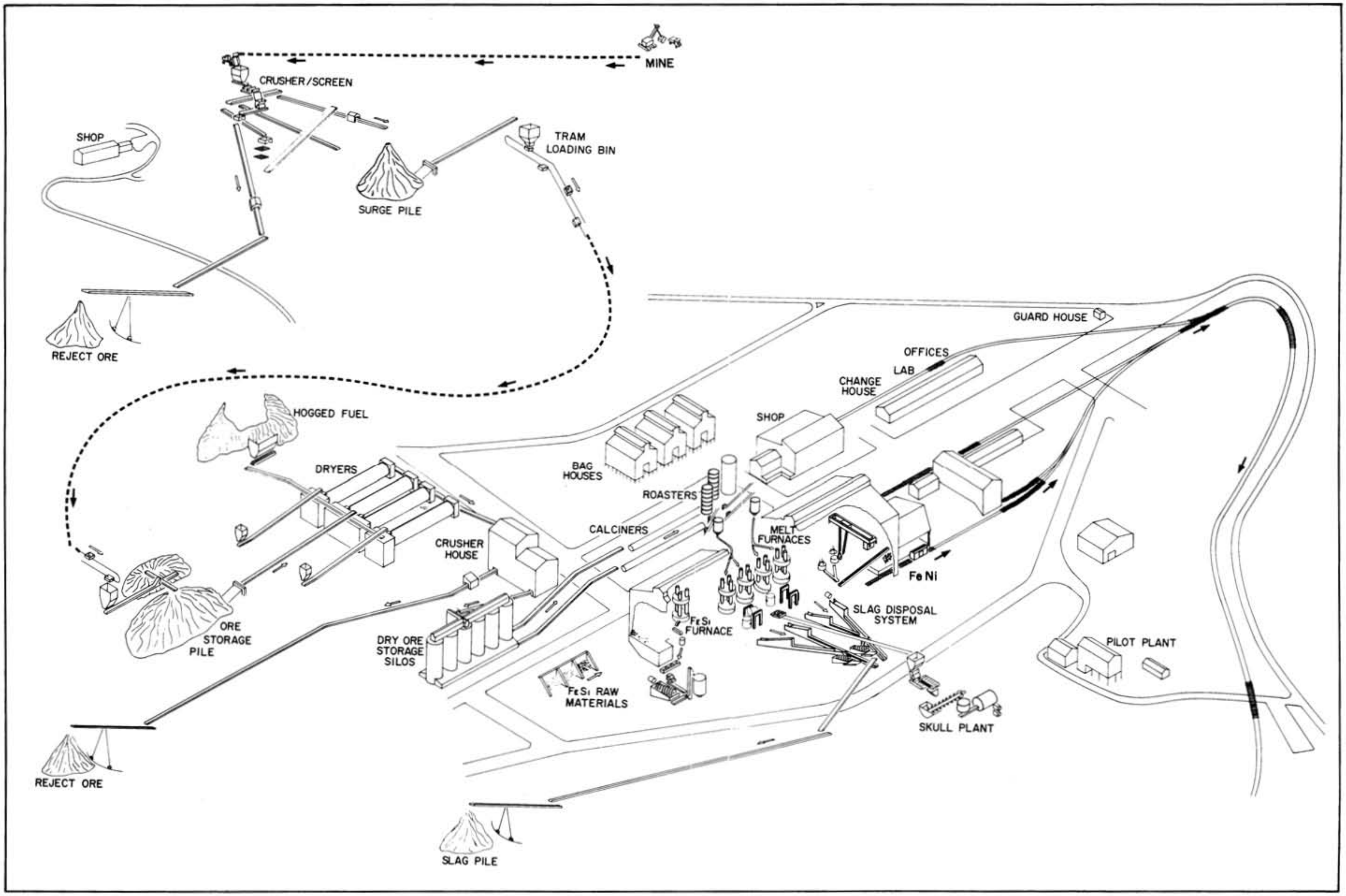
What kind of deposit is at Nickel Mountain?

The Nickel Mountain ore deposit is a laterite, with garnierite its chief mineral. Nickel Mountain itself appears to be an erosional remnant of an overthrust sheet containing peridotite which, when fresh, contains 0.2 percent nickel but is now weathered. The ore body was formed by the leaching and transporting downward of the nickel during the process of weathering.

The ore body is divided into three zones: (1) soil (bright red at the surface, grading into a yellow-brown at depth); (2) saprolite (light- to dark-green weathered peridotite); and (3)

Slagging off a refining furnace. (Photo courtesy Hanna Nickel Smelter Company)





Process whereby nickel is mined and smelted at Nickel Mountain, southwestern Douglas County, southwestern Oregon. (Drawing courtesy Hanna Mining Company and Hanna Nickel Smelting Company) box works (yellow-brown to bright-green). The soil contains 20 percent of the nickel resource, the saprolite 70 percent, and the box works the remaining 10 percent.

The deposit is made of six major areas that cover a total of approximately 600 acres. The average nickel grade in the crude ore presently under active development is approximately 1.0 percent.

How is the deposit mined?

The mining is by the multiple-bench open-pit method. The benches are at least 50 ft wide, with 20-ft vertical faces. Up to 80 percent of the ore can be dug without blasting. Conventional drilling and blasting are used on the remaining 20 percent. Pit-run ore is loaded by diesel shovels into 60-ton diesel trucks and hauled to the screening plant.

Can the ore be upgraded by flotation or other standard beneficiation?

No. Because of the mineralogy of the ore, the only upgrading that can be done must be based on the physical characteristics of the ore, such as softness or hardness, fineness or coarseness, and/or color.

How is the ore upgraded?

As the ore is being mined, large boulders called pit rejects are separated from the ore by the shovel operator and ultimately deposited on waste dumps. The boulders, which are mostly unweathered peridotite, contain low amounts of nickel. More upgrading takes place at the screening-crushing plant. The trucks dump the ore directly into the screening-plant feed hopper. A separation is made according to the size of the material, with the smaller going directly to the tramway surge pile and the larger to the crusher. After crushing, the material is visually classified and then directed either to the tramway or to the reject stockpile.

How does the ore get from the screening-crushing plant on top of Nickel Mountain to the smelter at the foot of the mountain?

An 8,300-ft tramway with a 2,000-ft drop connects the screening-crushing plant with the smelter. At the tramway, the ore is fed to the loading terminal, where it is loaded automatically into 50-cu-ft tram cars and conveyed downhill to the smelter storage stockpile.

The tramway runs continuously, carrying ore in the upright tram cars and returning the empty cars in an inverted position. The ore is discharged onto the stockpile by inverting the cars at the lower end of the tramway. A speed of 600 ft per minute is maintained by the braking action of the two 300-horsepower generators driven by the weight of the loaded tram cars. The braking action of the generators produces approximately 500 horsepower, which is used in the generation of electricity for the operation of the mine facilities.

How is nickel produced from the ore?

Ore from the stockpile is processed at the smelter to produce ferronickel containing approximately 50 percent nickel. Steps in the process include reclaiming of ore, drying, screening of fines, rejecting of lean rock by screening, crushing, sampling, calcining, melting, reducing to ferronickel, refining, casting, and recovering skull metallics.

The process whereby the ore is melted and reduced and the nickel refined is the most spectacular part of the entire operation. The ore is fed into the melting furnaces by gravity and further heated to a temperature of approximately 3,000° F., where it melts. The molten ore is then poured from the melting furnaces into ladles where the nickel extraction occurs.

Reduction of nickel and iron is accomplished by the Ugine process, which consists of adding a reducing agent containing metallic silicon to an oxide ore in the presence of molten ferrous metals and using vigorous mixing action for good contact of reductant and ore. In Hanna's smelter, crushed ferrosilicon containing 48 percent silicon is used to extract the metal. The ferrosilicon is produced in a separate electric furnace in the smelter. During a mixing cycle, nickel and iron are extracted from the molten material through a chemical reaction between the nickel ore and the ferrosilicon. The ferronickel is allowed to settle to the bottom of the ladle. The slag is poured off and granulated with high-pressure water jets. The nickel is then poured off into pigs for shipment.

What is done with the slag?

After the slag is granulated, it is transported by water to a large green slag pile. A small portion of the slag is sent to another company that screens the slag into different sizes, bags it, and ships it to California and elsewhere for use in sandblasting. The slag is also used for fill and sanding of highways.

How long will this operation last?

Reclamation plans on file with the Oregon Department of Geology and Mineral Industries state that mining will be going on at Nickel Mountain until at least the year 2003. Other deposits somewhat lower in grade are known to exist in Curry and Josephine Counties and might provide a source of ore after Nickel Mountain has been mined out.

Table 1. Summary of Hanna Mining Company's Riddle operation for 1979

Production—Ferronickel	42,250,415 lbs.
Nickel contained	21,787,960 lbs.
Ore mined	3,822,587 tons
Payroll	$16,000,000
Electrical power and fuels	$ 9,000,000
Environmental cost	$ 504,400
Property taxes	$ 298,400
County royalty fees	$ 275,000

What effect has the Riddle operation had on the local economy?

Employment in Douglas County is mainly timber dependent, which means that employment has had seasonal ups and downs and in the past has experienced wild swings up and down caused by the national demand for wood products. Because the plant provides year-round employment for more than 600 workers, the Riddle operation tends to provide a steady base level for the local economy. □

Industry expenditures for oil and gas exploration in Oregon, 1976-1980

1980	$25,700,000
1979	10,695,000
1978	4,608,000
1977	2,000,000
1976	2,000,000

ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time we will print abstracts of new acquisitions that we feel are of general interest to our readers.

THE STRUCTURE AND STRATIGRAPHY OF THE COLUMBIA RIVER BASALT IN THE HOOD RIVER VALLEY, OREGON, by Susan Timm (M.S., Portland State University, 1979)

The Hood River Valley, located 100 km east of Portland, Oregon, is in the transition zone between two geologic provinces—the High Cascades and the Columbia Plateau. The entire valley is probably underlain by Columbia River Basalt, but it crops out only on steep hillsides and in stream valleys. The base of the basalt is not exposed in the thesis area. The basalt is overlain by Pliocene and Quaternary basalt and andesite, volcanic sediments, and glacial debris.

The stratigraphy of the Columbia River Basalt is useful in determining the path of the basalt flows into western Oregon, in mapping the structure, and in reconstructing the tectonic development of the northern Oregon Cascades.

The detailed stratigraphy of the Columbia River Basalt in the Hood River Valley was determined through petrography, trace element chemistry, remanent magnetic polarity (RMP), and correlation of known flows in the field. The structure was determined by field observations and photo lineations and from stratigraphic correlations throughout the Hood River Valley.

The Columbia River Basalt exposed in the Hood River Valley belongs to the Yakima Basalt Subgroup and comprises the High MgO and the Low MgO geochemical types of the Grande Ronde Basalt and the Frenchman Springs and Priest Rapids Members of the Wanapum Basalt. Two remanent magnetic polarity boundaries are exposed in these basalt flows. They are the N2/R2 boundary within the Low MgO Grande Ronde flows and the R3/N2 boundary between the Priest Rapids and the underlying Frenchman Springs Members of the Wanapum Basalt.

The total thickness of the exposed Yakima Basalt is approximately 480 m. Extensive palagonite at the flow contacts and variation of thickness of groups of flows indicate that part of the area was a topographic low during much of the time the flows accumulated.

Two linear trends dominate the area. East- to northeast-trending faults and folds are cut by younger northwest-trending faults and dikes. An anticline plunges to the east across the southern part of Middle Mountain. A thick breccia zone in the Neal Creek drainage southeast of Middle Mountain marks a northeast-trending fault. The northeast structures are cut by numerous northwest-trending antithetic faults. The faults occur in a step-like pattern across the valley. The Hood River Fault bordering the east side of the valley has a right-lateral as well as vertical component.

The Hood River Valley does not appear to be a graben; rather it consists of many tilted blocks hinged to the southwest and dipping to the northeast. Flows on Middle Mountain on the west side of the valley are at the same elevation as correlative flows on the east side of the Hood River Fault.

GEOLOGY OF THE SOUTH-CENTRAL MARGIN OF THE TILLAMOOK HIGHLANDS; SOUTHWEST QUARTER OF THE ENRIGHT QUADRANGLE, TILLAMOOK COUNTY, OREGON, by Kenneth Allan Cameron (M.S., Portland State University, 1980)

The Tillamook Highlands is a largely unmapped volcanic pile located in the north end of the Coast Range of Oregon. The 36 sq mi of T. 1 N., R. 8 W., on the south-central margin of the Highlands, were chosen for detailed study.

The study area is composed of Eocene-age sedimentary and volcanic units which were deposited in a filling basin. The lowest units were deposited in moderate to deep marine waters; the uppermost were deposited subaerially.

Stratigraphically lowest is a unit composed of 800 m of rhythmically bedded, poorly indurated, sparsely fossiliferous, brown siltstone with rare interbeds of volcanic lithic sandstone. On the basis of fossil evidence (the pelecypods *Glycimeris* sp. and *Acila* sp.), it is believed that this material was deposited in moderate to deep marine water.

Conformably overlying the siltstone are 900 m of submarine volcaniclastic deposits with minor sedimentary sub-units and a large tuff lens. The major rock type is a zeolite-cemented flow breccia. Minor amounts of pillow lavas and hyaloclastites are found in the upper one-third of the unit. The sedimentary sub-units, consisting of immature volcanic feldspathic litharenites and tuffaceous shales, have a total thickness of 35 m. The shales are very fossiliferous, containing remains of the plants *Cornus* sp. (dogwood), *Picea* sp. (spruce), *Chamaecyparis* sp. (cedar), and *Ailanthus* sp. (Tree of Heaven) deposited in shallow water. These plants show that a warm, temperate climate existed in this area during the Eocene. The tuff lens is a deposit of water-worked crystal-vitric tuff. It has a maximum thickness of 100 m and an areal extent of over one square kilometer. It is characterized by an abundance of large (up to 3 cm) euhedral clinopyroxene crystals.

Conformably overlying the volcaniclastic unit are at least 900 m of subaerial pyroxene basalt in the form of individual flows 20 to 30 m thick. The basalt and volcaniclastic material interfinger for 100 m at the contact. Major oxide analysis shows that these two units are chemically identical and are probably the product of the same parent magma. The differing habit of the units is the result of differing environments of deposition; the volcaniclastics are submarine and the basalts subaerial.

The contact represents sea level during the extrusive period.

A large diabasic sill has intruded the marine siltstones. It has a glassy chilled margin with rudimentary columnar jointing which grades into white or green diabase with an ophitic core. Total thickness of this unit exposed in the study area is 300 m.

Structure is dominated by a regional dip of 18° to the northwest which is complicated by three generations of post-dip faulting. The first generation trends northwest, the second northeast, and the third east-west. All faults are vertical and show no strike-slip component.

Dikes with thicknesses over one meter are aligned, trending N. 30° W. This is a result of the regional stress pattern at the time of intrusion, probably compressional stress with σ_1 oriented east-west.

GEOLOGY AND METAMORPHIC PETROLOGY OF THE ELKHORN RIDGE AREA, NORTHEASTERN OREGON, by Eric Jordan Stimson (M.S., University of Oregon, 1980)

An investigation into the nature of regional and contact metamorphism of a part of the Elkhorn Ridge Argillite in northeastern Oregon and an associated greenstone body was carried out in the vicinity of the Late Jurassic Bald Mountain batholith. The mineralogy of the greenstones progresses from assemblages typical of the lower greenschist facies in the regionally metamorphosed rocks, through three zones of contact metamorphism as the batholith is approached. Pyroxene hornfels facies assemblages are developed in the highest grade rocks.

Clinochlore-bearing serpentinites are recrystallized to assemblages containing forsterite, enstatite, tremolite, and green spinel within 200 m of the batholith.

A greenstone body, previously mapped as a metamorphosed gabbroic intrusion, is shown to be a pile of intrusive and extrusive basic and intermediate rocks that were originally in depositional contact with the adjacent argillites. Post-depositional folding and thrust faulting has obscured this relationship.

THE GEOLOGY AND PETROLOGY OF THREE FINGERED JACK, A HIGH CASCADE VOLCANO IN CENTRAL OREGON, by Ellen Ingraham Davie, II (M.S., University of Oregon, 1980)

The eruptive history of Three Fingered Jack is characteristic of many of the coherent volcanoes of the High Cascade Range. First, a pyroclastic cone formed on the underlying shield lavas and was then followed by flows and pyroclastic material which accumulated to form the main cone. Numerous dikes radiate outwards from a late stage plug of micronorite that slightly deformed adjacent layers of tephra. Subsequent flows of olivine-augite basalt occurred on the north and south flanks of the volcano.

Major- and trace-element abundances indicate that in the area of Three Fingered Jack different units of flows represent discrete batches of parental magma. Jorn Lake basalt of the underlying shield and basaltic andesite of Three Fingered Jack are exceptions to this general rule. Petrology indicates that these lavas crystallized at high and low pressures; basaltic andesite differentiated from basalt as a result of prolonged crystal fractionation. □

Don't trespass on mining claims

High mineral prices and the onset of fine weather lure people out to roam spaces that may not be open, even though they appear to be. The public needs to be reminded that mining claims are property in the highest sense of the term. A patented claim has the same legal status as a house in town. Unauthorized entry on such land is prohibited as strongly as on any private premises. Trespassing can bring criminal prosecution.

The public may not be aware that unpatented mining claims are also private property, even though management of surface resources and vegetation is a function of a public agency such as the Bureau of Land Management or the U.S. Forest Service. The United States, its licensees, or permittees are required by law to avoid interference with the mining locator's prospecting, mining or processing activities, or activities reasonably incident thereto, as well as the miner's buildings, equipment, and improvements on the claim.

Both Federal and State law protect the miner against vandalism. It is unlawful to deface, remove, pull down, or injure or destroy, any location stake, side post, corner post, landmark, or monument, or to tear down, deface or alter any posted or written notice on a mining claim. Any damage to the miner's cabin or equipment or any breaking and entering or injury to his property is punishable as a crime. People who like to roam the great outdoors should be careful to obtain permission before they invade areas that have been segregated from the public domain, and even on the public domain they should remember to observe good manners towards public property also. □

—Bohemia Mine Owners Association

(New open-file reports, *continued from page 74***)**

Open-File Report 0-80-10, *Preliminary Geology and Geothermal Resource Potential of the Alvord Desert Area, Oregon,* contains geothermal data from the Alvord Valley, which lies east of Pueblo and Steens Mountains in southeastern Oregon. Included in the 57-page text are total field aeromagnetic anomaly, audio-magnetotelluric apparent resistivity (27 and 7.5 hertz), and simple Bouguer gravity anomaly maps of the area. Accompanying the text are a one-color reconnaissance geologic map and a two-color preliminary geothermal resource map (scale 1:250,000). Cost of Open-File Report 0-80-10 is $7.00.

Previously announced open-file reports in this series include 0-80-2 (Belknap-Foley area of the central Western Cascades), 0-80-3 (Willamette Pass area of the central Western Cascades), 0-80-6 (northern Harney Basin), and 0-80-7 (southern Harney Basin), which sell for $5.00, $5.00, $7.00, and $10.00, respectively.

All of these open-file reports are available for inspection or purchase at the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201. Payment must accompany orders of less than $20.00. □

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