Geology of the Late-Eocene Clarno Unit, John Day Fossil Beds National Monument, Central Oregon

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Abstract

Through detailed stratigraphic section description and lithostratigraphic mapping in the type area of the Eocene Clarno Formation we have generated a geologic framework for the numerous fossil sites in the Clarno Unit of the John Day Fossil Beds National Monument. Two widespread conglomeratic units of andesitic composition are recognized in the area and are separated by red claystones (paleosols). The lower, Palisades unit consists of channel and floodplain debris-flow conglomerates and hyperconcentrated flood flow or lahar runout deposits. The overlying Hancock Canyon unit also contains channel and floodplain debris-flow conglomerates, but has in addition fluvially reworked conglomerates and pebbly sandstones, reworked tuff beds, a distinctive amygdaloidal basalt flow and the Nut Beds fossil site. The Palisades unit is interpreted as a debris-flow apron on which there was little lateral fluvial reworking. The Hancock Canyon unit is interpreted as a debris-flow apron to a braidplain in an area of complex topography, with multiple sources of volcanic sediments. Above these two debris-flow dominated units are the thick, but discontinuous, claystones of Red Hill. These very clayey red beds record a long period of volcanic quiescence, slow floodplain aggradation and long periods of tropical and subtropical soil formation. A climatic change is inferred during the accumulation of the red beds from the presence of very strongly developed Ultisollike paleosols in the lower half of the unit and well developed, Alfisollike paleosols in the upper half. The changes between these two packages of paleosols may reflect climatic cooling and drying during Late Eocene times. The overlying siltstones of the Mammal Quarry and associated andesite of Horse Mountain accumulated in response to renewed andesitic volcanism. The Mammal Quarry unit consists of tan and gray clayey sandy siltstones, gravel conglomerates and a basal andesitic breccia. The Late Eocene mammal assemblage of the Mammal Quarry was preserved in a channel and floodplain sequence that accumulated rapidly in response to the eruption of the large and widespread flows of the andesite of Horse Mountain.

Introduction

The scenic high desert of north-central Oregon contains a colorful volcanic and alluvial sequence of Tertiary age. The combination of low precipitation (320 mm annually in Antelope) and seasonal temperature extremes (January mean of -1°C and August mean of 19°C; Ruffner, 1978) favors xerophytic, sparse vegetation and good exposures. In contrast, fossil flora of Eocene age from sites in the Clarno Unit indicate paratropical conditions analogous to that of modern southeast Asia (Manchester, 1981, in press). The transition from steamy jungles of the past to the open ranges of today is recorded in a copious fossil record of a diverse flora, invertebrates, freshwater fish, reptiles, and mammals in this region (Stearns, 1900; Stearns, 1906; Merriam and Sinclair, 1907; Dallas, 1920; Merriam and others, 1925; Chaney, 1925; Stirton, 1944; Scott, 1954; Downs, 1956; Cavender, 1968; Mellet, 1969; Naylor, 1979; Manchester, 1981; Wolfe, 1981a and 1981b; Ashwill, 1983; Martin, 1983; Rensberger, 1983; Manchester and Meyer, 1987; Hanson, 1989). These profound paleoenvironmental changes are also reflected in a sequence of paleosols ranging in age from Middle Eocene to the present (Fisher, 1964; Retallack, 1981, 1991a, 1991b; Pratt, 1988; G.S. Smith, 1988). Three units of the John Day Fossil Beds

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National Monument (Sheep Rock, Clarno, and Painted Hills) were established for the protection and appreciation of these significant geologic and paleontologic resources.

This paper outlines geologic and paleoenvironmental findings of a 3-year study of the Clarno Unit. We describe new informal lithostratigraphic subdivisions of the Clarno Formation, with stratigraphic and paleoenvironmental data and preliminary interpretations. Data presented in this report were largely gathered from measuring and describing stratigraphic sections of outcrops, with extensive trenching to exposed fresh rock beneath badlands mantled with soil.

Basement rocks in north-central Oregon consist of highly deformed metasediments of Permian age. In some areas, these are overlain by a thick sequence of Cretaceous marine rocks. In the Clarno area, phyllites and argillites of uncertain affinity (either Permian or weakly metamorphosed Cretaceous shales) are exposed in the Muddy Ranch dome. These basement rocks are intruded and overlain by andesitic volcanic and alluvial rocks of the Clarno Formation, which ranges in age from Middle to Late Eocene, some 54 to 37 Ma (McKee, 1970; Enlows and Parker, 1972; Rogers and Novitsky-Evan, 1977; Manchester, 1981; Vance, 1988; Walker and Robinson, 1990). Volcanic plugs, lava flows, and lahars with convergent-margin andesitic compositions and textures indicate accumulation in and around andesitic volcanic cones of the Eocene Clarno volcanic arc (Noblett, 1981; Suayah and Rogers, 1991; White and Robinson, 1992).

Rhyolitic ash-flow tuff and dacitic to rhyodacitic airfall tuffs are conspicuous in the latest Eocene, Oligocene, and Early Miocene (22-to 39-my) John Day Formation (Peck, 1964; Woodburne and Robinson, 1977; Robinson and others, 1990; Bestland and others, 1993). These primary pyroclastic, alluvial and lacustrine deposits were supplied with volcanic ash from vents to the west in the present area of the western Cascades (Robinson and others, 1984). Thus, the Clarno and John Day formations of central Oregon record a Late Eocene westward jump of the subduction zone in the Pacific Northwest and a corresponding change from Clarno andesitic volcanism to Cascade volcanism and John Day back-arc basin deposition.

The Clarno Unit-Hancock Field Station area can be divided into two areas based on structure: 1) relatively flat lying strata of Horse Mountain, and 2) these same strata folded along a NE-SW fold limb. Other smaller folds are present in the area, but the NE-SW fold dominates the local structure. This fold has the same orientation as the Muddy Ranch dome (Robinson, 1975), southwest of the project area. The fold dies out in the northeastern part of the project area (fig. 1). In the Clarno Unit area, the geologic sequence is complicated by this NE-SW fold limb, intrusion of a dacitic dome, another small structural dome, and laterally variable volcanic facies.

Stratigraphic Subdivisions

Lower Clarno conglomerates—A sequence of bouldersized, matrix-supported conglomerates exposed just west of Hancock Canyon is the oldest and most deformed unit in the mapped area. Its clasts are boulders and cobbles of altered plagioclase porphyritic andesite. Recognized first by Hanson (1973), the unit lacks tuff beds or paleosols and forms the southwestern half of a structural dome. Another but less likely possibility is that this unit is part of the Palisades conglomerate unit that has been locally faulted and folded.

Hancock Dacite Dome—A plagioclase-hornblende porphyritic dacite body is exposed in the hills and gullies northeast of Hancock Field Station (fig. 1). Excellent exposures of this unit in tributary gullies of Hancock Canyon indicate that it is a homogenous igneous body, not boulders of dacite weathering out of a debris-flow. However, intrusive features such as baking, veining, alteration and mineralization of the surrounding country rock were not observed. Boulder deposits containing clasts exclusively of this dacite are present in well-developed paleosols overlying the dacite. Thus, the dacite body was an erosional feature that was mantled by colluvium and soils. The Hancock dacite dome is also pervasively altered, probably by deep weathering during the Eocene.

Main Sequence

In the study area, the Clarno Formation contains laterally extensive and mappable lithostratigraphic units (fig. 1). The units are of two types: 1) andesitic debris-flows and 2) andesite lava flows. Smaller scale lithostratigraphic units, such as clayey red beds, basalt flows, and tuff beds are also present in this area (fig. 2). These large debris-flow and andesite-flow units constitute the majority of the cliffs along the John Day River in the area south of Clarno bridge and along the western part of Pine Creek.

Andesite of Pine Creek—The base of the coherent section mentioned above consists of a thick andesite unit referred to as the andesite of Pine Creek. The unit consists of thick lava flows of dark colored pyroxene-plagioclase andesite that are commonly altered by varying degrees. The unit has a very

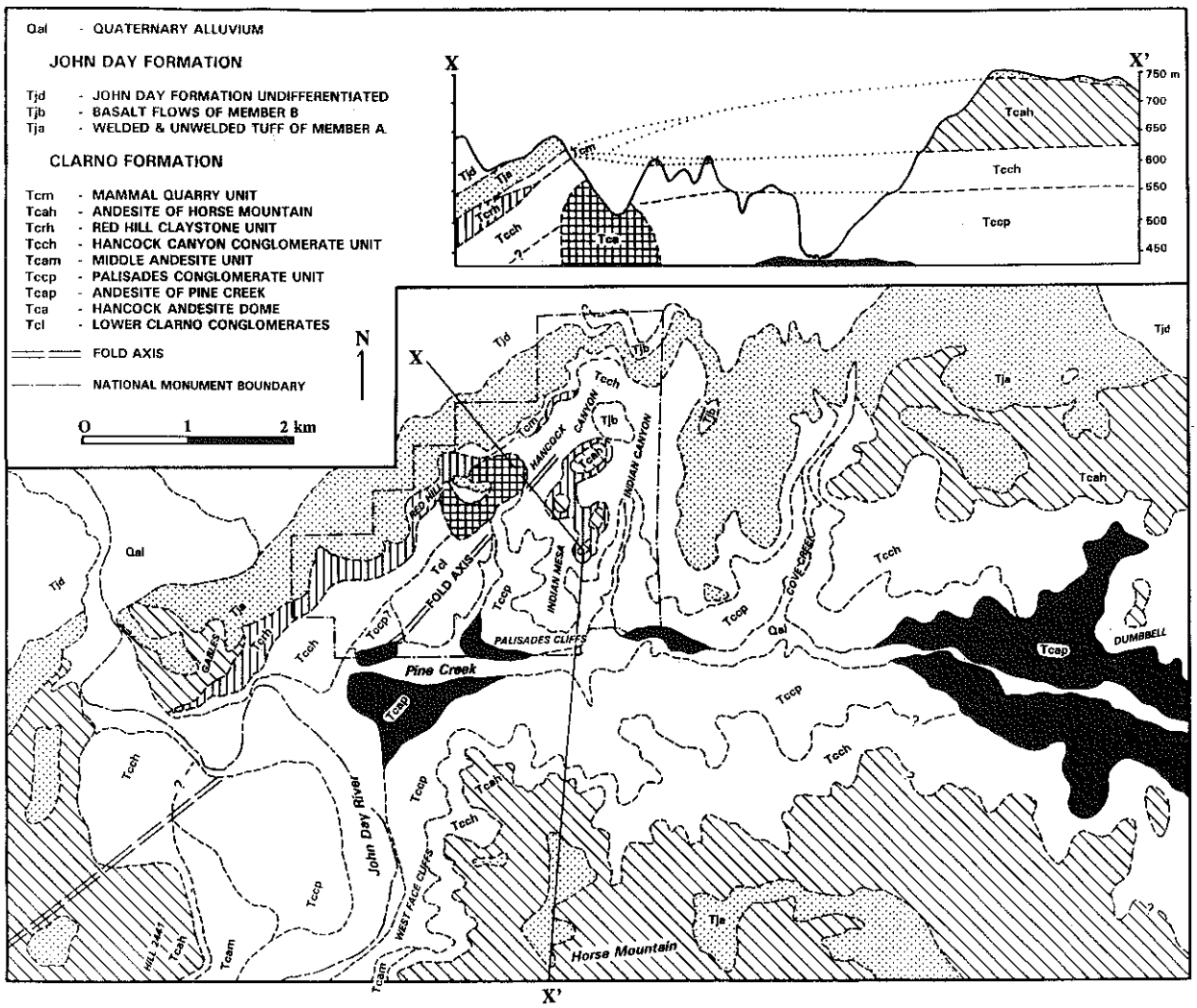
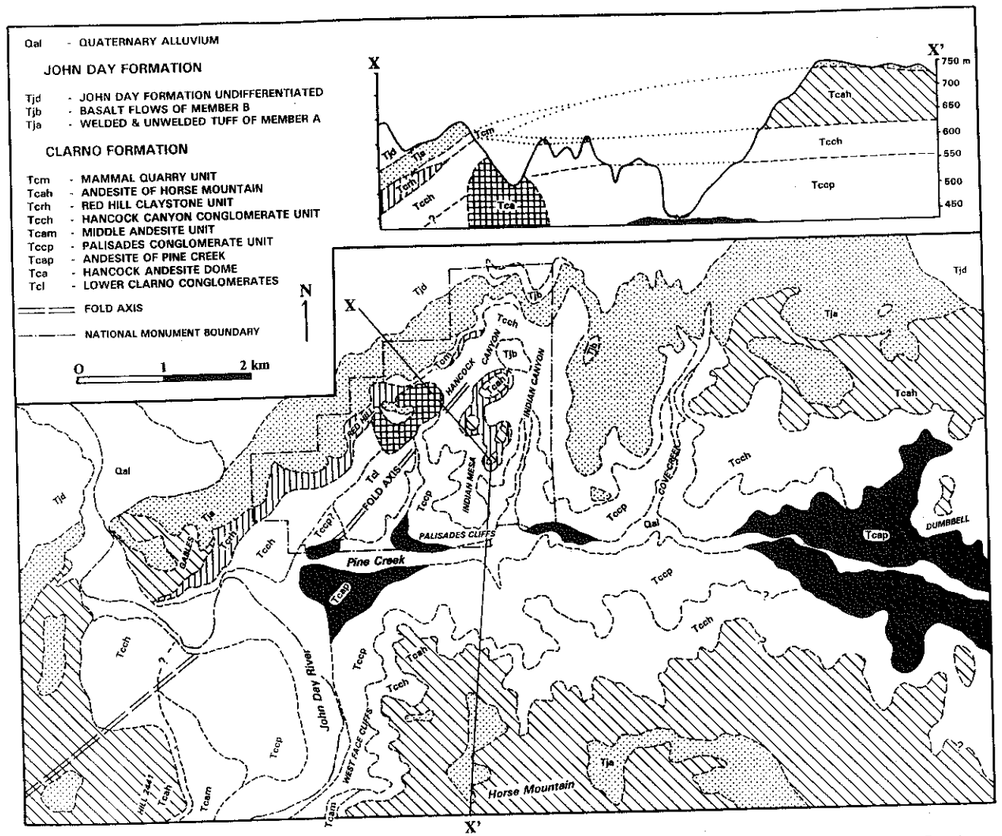


Figure 1. Geologic sketch map of the Clarno Formation from the John Day River near Clarno bridge and along Pine Creek. Quaternary landslide deposits have been omitted for clarity.

irregular upper surface that is mantled by a well-developed reddish saprolite breccia. Pockets of red and white claystones are preserved between the andesite and overlying debris-flows. The clayey saprolite and claystones erode to form an erosional bench which is occupied in part by the modern Pine Creek floodplain. Basal sapping of the overlying debris-flows due to the erodability of these claystones is partly responsible for the Palisades cliffs. East of Cove Creek, the basal andesite unit is again extensively exposed. Thick, autobrecciated andesite flows are present beneath hill 2932 (Dumbbell Hill) and include several basaltic andesite flows that onlap the highly porphyritic andesite and andesite breccia from the Dumbbell Section (fig. 2).

Conglomerates of the Palisades—Onlapping the irregular surface of the andesite of Pine Creek is a thick sequence of matrix-supported andesitic debris-flows. This unit has weathered into the spectacular hoodoos along Pine Creek and in the West Face cliffs along the John Day River (fig. 1). Most of the debris-flows are of the matrix-supported, moderately clast-rich floodplain debris-flow type (Scott, 1988). In the Palisade cliffs, numerous clast-rich, channelized debris-flows are present, some being clast supported at their base. Hyperconcentrated flood flow deposits (in the sense of G.A. Smith 1987; and Nemec and Muszynski, 1982) are also common. These grade into debris-flow deposits and occur as interbeds between debris-flows. Well exposed at approximately the middle of the member are several thin, green, clayey paleosols with wood fragments and leaf impressions. These thin, green paleosols are present in the Palisades section and are well exposed in the lower part of the cliffs along the John Day River. Above the green clayey horizons is a tuffaceous breccia layer that grades up into a massive debris-flow. This debris-flow weathers brownish-orange



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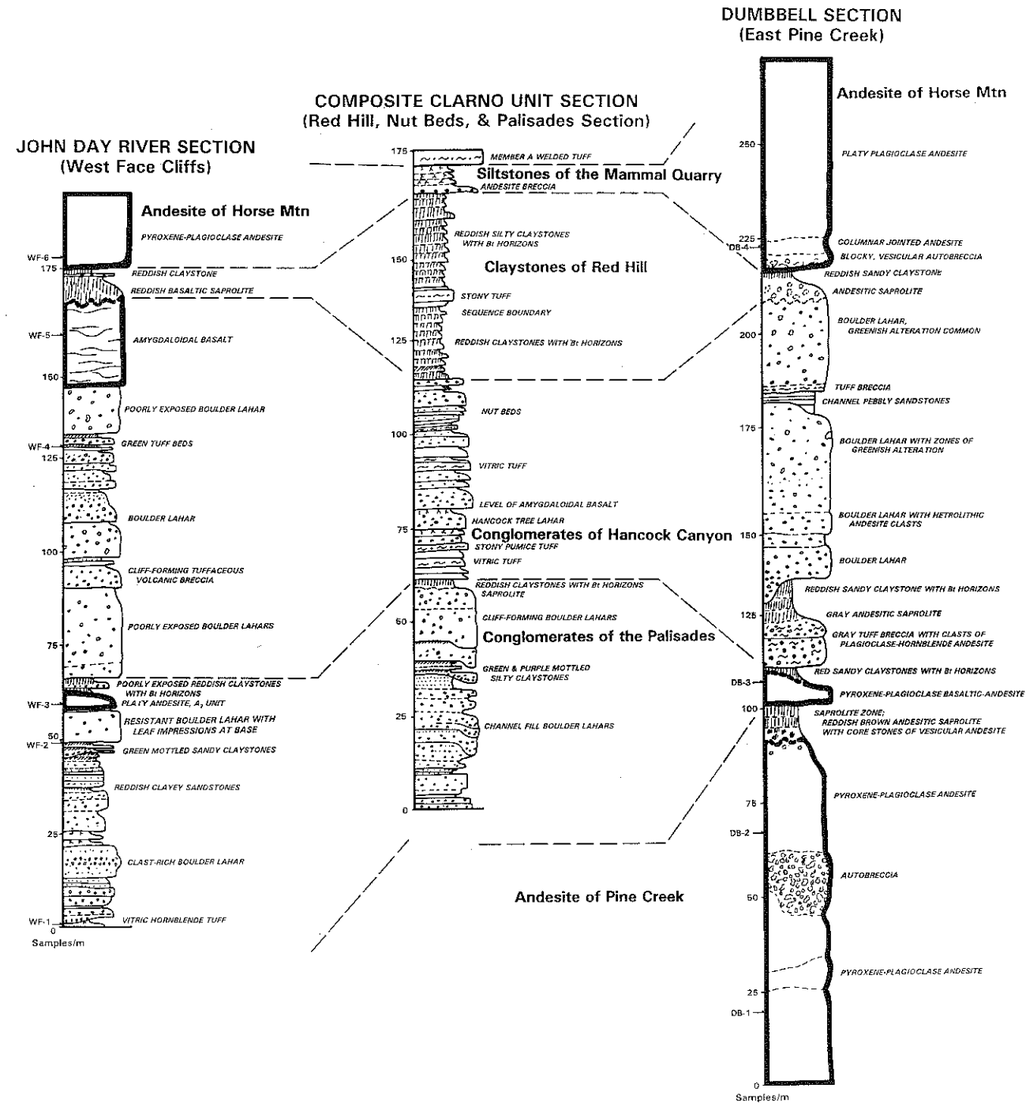

Figure 2. Stratigraphic fence diagram of the Clarno Formation.

and crops out prominently along the West Face cliffs. East of Cove Creek, the Palisades unit debris-flows onlap, thin, and pinch-out against the andesite of Pine Creek (fig. 1 and 2).

Middle Clarno andesite—This thick andesite is locally present in the southern part of the project area along the John Day River south of Clarno bridge. The unit makes up the lower half of the monolithic buttes on the west side of the John Day River (hills 2441 and 2373, Clarno 7.5 min. series) where the unit fills a paleovalley cut into the conglomerates of the Palisades on the west side of the river. The unit, a blocky, dark-colored, pyroxene-plagioclase andesite, is onlapped by conglomerates of Hancock Canyon. Saprolite mantles the andesite and in places red claystones (paleosols) are present above the andesite. Where the andesite is absent, reddish claystones overlie the conglomerates of the Palisades. These claystones erode to form a bench

on the mesa between Hancock Canyon and Indian Canyon (Indian Mesa on fig. 1). This bench is also present on the north and west sides of Horse Mountain.

Conglomerates of Hancock Canyon—Overlying the red claystones at the top of the conglomerates of the Palisades are the conglomerates of Hancock Canyon. This unit includes tuffaceous beds and a distinctive basalt flow, but is dominated by matrix-supported boulder debris-flows. The amygdaloidal, high-silica basalt flow is laterally extensive, mappable, and stratigraphically in the upper half of the unit. The basalt is a holocrystalline, plagioclase and pyroxene basalt with common pahoehoe flow structures and local columnar jointing. The basalt can be mapped from the Hancock Field Station area to the Gables and is thickest in the West Face cliffs, but is not present east of Indian Canyon.

The conglomerates of Hancock Canyon contain the Nut Beds fossil site and the Muddy Ranch Tuff, both dated at 44 Ma; C. Swisher obtained a date of 44 Ma from a plagioclase separate from a reworked crystal tuff in the Nut Beds using the $^{40}Ar/^{39}Ar$ method (pers. comm., 1992) and Vance (1988) obtained a fission-track date of 44 Ma from zircon crystals in the Muddy Ranch Tuff (also known as the Rajneesh Tuff) near the Gables. The Muddy Ranch tuff is stratigraphically below the Nut Beds, also dated by Vance (1988) at 44 Ma. Many large, well-preserved *Cercidiphyllum* (katsura) and *Macginitea* (sycamore) permineralized tree trunks and limbs are in this unit, similar to the "fossil forests" found in comparably-aged Lamar River Formation on the Yellowstone plateau (Dorf, 1964).

Claystones of Red Hill—In the Clarno Unit area, a thick sequence of reddish and grayish-purple claystones is present above the Hancock Canyon conglomerate unit. The unit is 59 m thick in the Red Hill area (fig. 2) but thins dramatically to the east (fig. 1). In the cliffs on the west and north sides of Horse Mountain, only a reddish saprolite with a thin clay layer is present at this stratigraphic level. The unit at Red Hill contains a lower reddish paleosol sequence of very deeply weathered Ultisollike paleosols and an upper, less well-developed, Alfisol-like paleosol sequence (G.S. Smith, 1988; Retallack, 1991a). A stony tuff bed divides the two paleosol sequences.

Andesite of Horse Mountain—This thick andesite unit is extensively exposed in the project area where it caps much of Horse Mountain. The unit consists of platy to blocky andesitic material, which varies from pyroxene-plagioclase andesite to very porphyritic plagioclase dacite with traces of hornblende. Along the west and north sides of Horse Mountain, the unit overlies a thick red saprolite developed on the amygdaloidal basalt flow in the Hancock Canyon unit. Ramplike flow structures are common in lava flows exposed in the West Face cliffs. The base of the unit dips gently to the west, probably following a paleoslope.

Siltstones of the Mammal Quarry—The tan, clayey siltstones and cobble conglomerates of the Mammal Quarry beds are only locally present in the Red Hill-Indian Canyon area. A diverse vertebrate fauna has been excavated from the Mammal Quarry, in the uppermost Clarno Formation below member A of the John Day Formation (Hanson, 1973 and pers. comm., 1993). Several taxa in this assemblage have close affinities with Asiatic faunas of the early Duchesnean North American Land Mammal Age. Pratt (1988) described Inceptisollike paleosols from the Mammal Quarry. By her interpretation, the fossil remains accumulated as carcasses and were disarticulated in a fluvial point bar. Stratigraphic work during this project has shown that the Mammal Quarry unit was deposited in response to the eruption of the andesite of Horse Mountain. At several exposures east of the Mammal Quarry, red claystones of the Red Hill claystone unit are overlain by andesite breccia which can be traced to outcrops of andesite of Horse Mountain. This breccia grades into the tan clayey siltstones of the Mammal Quarry unit.

Welded tuff of member A—Rhyolitic pyroclastic volcanism of the John Day Formation is first recorded in north central Oregon by an ash-flow tuff redated at 39 Ma (Bestland et al., 1993). The John Day Formation in its western facies has been divided into informal members A-I based largely on the stratigraphy of ash-flow tuff sheets (Peck, 1964; Swanson and Robinson, 1968; Robinson, 1975). The distinctive and widespread ash-flow tuff of member A is very useful in delineating the Clarno surface at the onset of John Day volcanism.

Distinctive basalt flows and associated intrusions immediately overlie member A. They consist of aphanitic to subglassy basalt that weathers into cobble-sized blocks. These basalts correlate with the member B trachyandesites (Peck, 1964) well developed in the Ashwood area (Swanson, 1969), but also mapped in this area (Robinson, 1975).

Discussion

The stratigraphic framework of these Clarno Formation lithostratigraphic units and corresponding fossil sites is complicated by rapid lateral stratigraphic changes. These changes are largely

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Discussion

The stratigraphic framework of these Clarno Formation lithostratigraphic units and corresponding fossil sites is complicated by rapid lateral stratigraphic changes. These changes are largely

caused by erosional disconformities between units, original topography of many volcanic units, and local accumulation of some types of volcanic units (i.e. lava flows). Folding and faulting in the Clarno area and onlapping of the Hancock andesite dome have added to the local stratigraphic complexity. On a regional basis, the Clarno Formation remains largely undivided due to these factors as well as the lack of widespread Clarno marker beds.

The conglomerates of the Palisades are interpreted as a debris-flow apron because they consist of debris-flow deposits and largely lack reworked or fluvial interbeds. This Palisades debris-flow apron was probably part of the constructional edifice of an active volcano. A volcanic apron to braidplain depositional setting is interpreted for the conglomerates of Hancock Canyon because they contain a variety of deposits including fluvial conglomerates, thin, reworked tuff beds, and matrix-supported debris-flows. The variety of deposit types indicates a floodplain setting that received material from a variety of sources. Floodplain aggradation was largely controlled by volcanic eruptions and their corresponding debris-flows. During volcanic hiatuses there was fluvial reworking. On the earlier Palisades volcanic apron, in contrast, incision of the deposits predominated during volcanic hiatuses thus giving rise to deeply nested channelized debris-flows.

Within the Clarno area are numerous fossil plant localities (including several new sites, revealed during excavation for this study) that indicate apparently dissimilar climates. The classic Nut Beds site yields plant fossils strongly indicative of a tropical to paratropical climate (Manchester, 1994). In contrast, at the same stratigraphic level and in a similar debris-flow depositional environment, the fossil plants found in Hancock Canyon suggest temperate conditions. These contrasting floral types are probably not different stages in ecological succession, because early successional fossil soils and plants are also found in this unit, and are dominated by horsetails and ferns. It is more likely that the Nut Beds flora represents a lowland rainforest, like the selva of tropical Mexico, whereas the Hancock Tree flora represents a higher altitude forest of cooler climatic affinities like the *Liquidambar* oak forests of Mexico (Gomez-Pompa, 1973). Thus, according to this interpretation, the conglomerates of Hancock Canyon contain the ecotone between these two distinct forest types: an upland paratropical forest and a lowland tropical forest.

Deciduous forests of volcanic and other Eocene uplands were an important source of new plant communities as paleoclimate became cooler and drier from Middle to Late Eocene and then again in the Early Oligocene (Wolfe, 1987). The vertebrate faunas also reflect these climatic shifts. Fossil mammals of the Clarno Nut Beds are comparable to the Middle Eocene forest-dwelling faunas of much of North America. The Mammal Quarry fauna however, represents an immigration of new mammals from Asia, adapted to cooler and drier conditions. The Clarno volcanic arc provides some of the earliest evidence of these later faunas and may represent a staging area for the widespread North American faunas of the Chadronian North American Land Mammal Age (Retallack, 1991a).

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