Sequence stratigraphy of the Eocene-Oligocene transition: examples from the non-marine volcanically influenced John Day Basin

Erick A. Bestland[1], Gregory J. Retallack[1], and Theodore Fremd[2]

[1]*Department of Geological Sciences, University of Oregon, Eugene, OR 97403;* [2]*John Day Fossil Beds National Monument, 420 W. Main, John Day, OR 97845*

Introduction

This field trip log is for a two day excursion in the high desert of central Oregon from Prineville to the Painted Hills near Mitchell and finishing in the Clarno area (Fig. 1). The trip emphasizes Tertiary paleosol sequences in both the late Eocene Clarno Formation and the late Eocene to early Miocene John Day Formation. It summarizes the geology and stratigraphy of selected areas in the Painted Hills Unit and the Clarno Unit of the John Day Fossil Beds National Monument. Most of the field stops are on National Park Service property where walking and digging on the badland slopes are prohibited.

Paleoclimatic setting of paleosol sequences in the John Day Basin

The scenic high desert of north-central Oregon contains colorful volcanic and alluvial rocks of Tertiary age. Due to low rainfall (320 mm annually in Antelope) and temperature extremes (January mean of –1 C and August mean of 19 °C) (Ruffner, 1978) the landscape supports desert scrub of sage and juniper and numerous badlands. In contrast to the present vegetation, fossil plants of Eocene age from the Clarno Formation indicate a climate much wetter, warmer and more equable than at present, more like that of modern lowland Panama or southern China (Manchester, 1981; Manchester, in press). The transition from the steamy jungles of the past to the open ranges of today is recorded in a copious fossil record of plants, non-marine snails, freshwater fish, reptiles, and mammals in this region (Merriam and Sinclair, 1907; Merriam and others, 1925; Chaney, 1925, 1927; Scott, 1954; Downs, 1956; Cavender, 1968; Wolfe, 1981a and 1981b; Ashwill, 1983; Rensberger, 1983; Manchester and Meyer, 1987; Hanson, 1989).

Profound paleoenvironmental changes are also reflected in thick successions of paleosols ranging in age from middle Eocene to the present (Fisher, 1964; Fisher, 1968; Retallack, 1981, 1991a, 1991b; Pratt, 1988; G.S. Smith, 1988; Bestland and others, 1993). In both the Clarno and John Day formations, packages of paleosols and their corresponding alluvial deposits have been identified and found to span approximately 2-3 million years each (Retallack, 1991a and 1991b; Bestland and others 1993, 1994). This field trip will examine exposures of large-scale truncation surfaces that separate paleosol packages and also examine the lithologic change in paleosols spanning the Eocene-Oligocene transition. Conformable packages of paleosols and alluvial deposits are interpreted as non-marine equivalents of the offlap-onlap relationships of sequence stratigraphy (Haq and others, 1986). The truncation surfaces that separate them are interpreted as stratigraphic sequence boundaries. The change in environmental conditions from one sequence to the next is recorded in the degree of soil development, clay mineralogy, bulk rock chemistry and soil structures of different paleosol types. Global, step-wise climatic change is interpreted to be the cause of these changes. New Ar/Ar age determinations allow for preliminary correlation of the sequences identified in the Clarno and John Day formations with the global record of climatic change from deep sea cores as well as with continental North American and European formations. The sequence boundaries, or truncation surfaces, correlate with periods of rapid climate change, whereas the paleosol and alluvial packages were deposited during climatically stable periods.

Regional Geology

Basement rocks in north-central Oregon consist of highly deformed metasedimentary rocks of Paleozoic and Mesozoic age (Fig. 1). These rocks are overlain by a thick sequence of Cretaceous marine strata. Both of these units are intruded and overlain by andesitic volcanic and alluvial rocks of the Clarno Formation, which ranges in age from middle Eocene to late Eocene, some 54 to 37 million years old (McKee, 1970; Enlows and Parker, 1972; Rogers and Novitsky-Evan, 1977; Manchester, 1981; Vance, 1988; Walker and Robinson, 1990). The Clarno Formation represents subduction related andesitic volcanism, probably on thin continental crust (Noblett, 1981). The formation is dominated by andesite lava flows and coarse-grained volcaniclastic strata that were deposited in alluvial aprons and braidplains that flanked active volcanoes (White and Robinson, 1992). The variety of paleosols present in the Clarno Formation can be grouped into the following general types; clayey alluvial paleosols of former floodplains, weakly developed paleosols interbedded with debris flows and andesite lava flows, and residual paleosols with thick saprolite zones between major lithostratigrapic units.

Rhyolitic ash-flow tuffs and dacitic to rhyolitic tuffs are conspicuous in the latest Eocene, Oligocene and early Miocene (39-22 million years) John Day Formation (Hay, 1962, 1963; Peck, 1964; Fisher, 1967; 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 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 (Robinson and others, 1984).

From: Swanson, D.A., and Haugerud, R.A., editors, Geologic field trips in the Pacific Northwest: 1994 Geological Society of America Annual Meeting

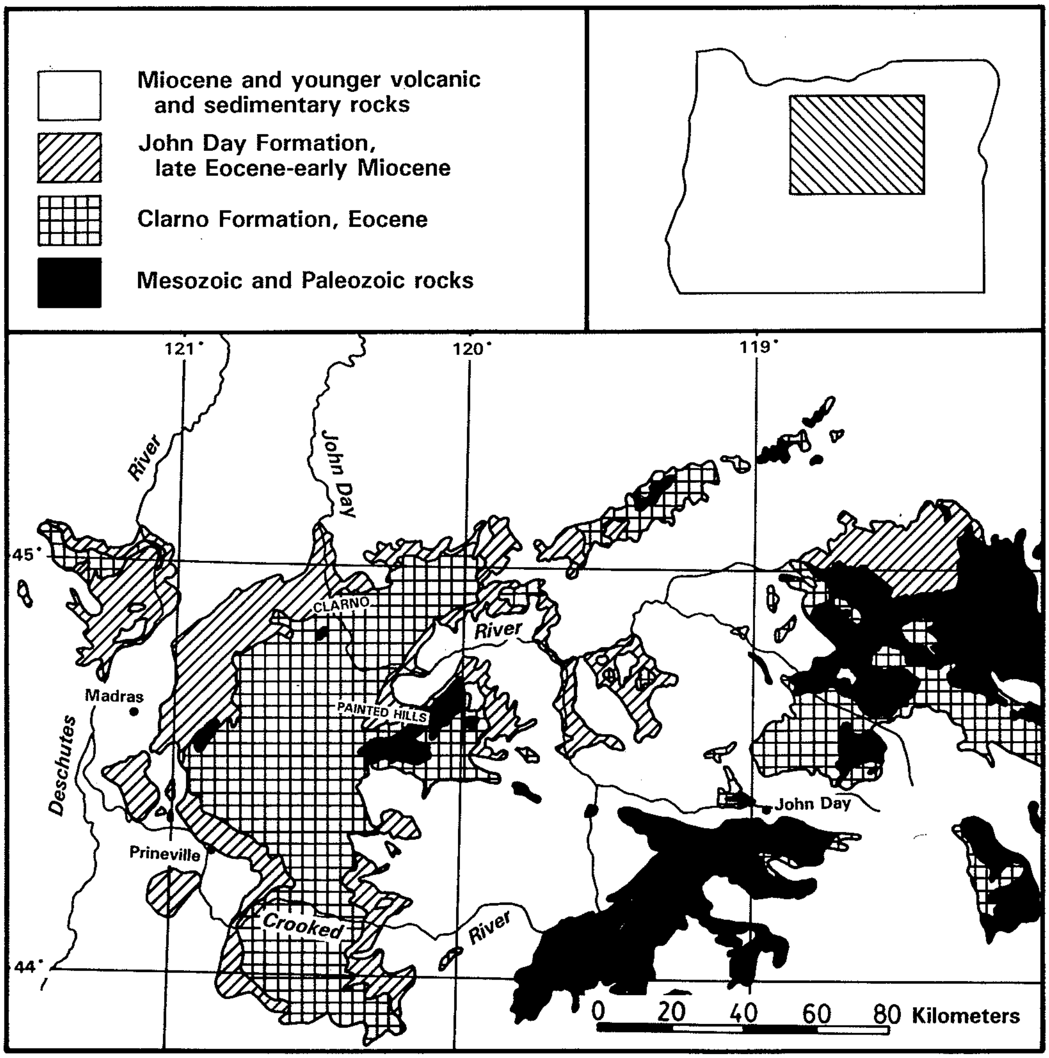

FIGURE 1. Location map of north-central Oregon, modified from Walker (1977) and Walker and Robinson (1990), showing the distribution of the Clarno and John Day formations and Mesozoic and Paleozoic basement rocks.

The John Day Formation is divided into an eastern and western facies by the Blue Mountains uplift (Robinson and others, 1984). The western facies near Clarno and Madras is informally divided into members A through I based largely on the presence at the base of several distinctive ash-flow tuffs (Peck, 1964; Swanson and Robinson, 1968; Swanson, 1969; Robinson, 1975). The western facies contains coarse-grained volcaniclastic deposits, welded ash-flow tuff sheets, and a variety of lava flow units including trachyandesite flows of member B, rhyolite flows of member C, and alkaline basalts in member F. The eastern facies around the Painted Hills and to the east is divided into four formal members (Fisher and Rensberger, 1972), from bottom to top the Big Basin Member (red claystones), Turtle Cove Member (green and buff tuffaceous claystones), Kimberly Member (massive tuff beds), and Haystack Valley Member (tuffaceous conglomerates). The Painted Hills contains the ash-flow tuffs of member A and the informally named "Picture Gorge ignimbrite" (Fisher, 1966) correlated with member H of the western facies. We informally divide the Big Basin Member into a lower, middle and upper member and divide the Turtle Cove Member into a lower and upper member based on the position of "Picture Gorge ignimbrite" (Fig. 2).

Road Log

Day 1. Prineville to Hancock Field Station

Mileage

0.0 Mileage starts at the Ochoco Mall on the east side of Prineville just off Highway 26. Prineville sits on Quaternary alluvium that perhaps was dammed by intracanyon basalt flows which flowed into the Crooked River drainage just downstream from Prineville. The rim rock on the west side of town is an early Pliocene lava flow that is near the top of the Deschutes Formation, and probably correlative with lava flows dated elsewhere in the Deschutes Formation at 4.0 Ma (G.A. Smith, 1986a). North of Prineville, the Blue Mountain anticline rises above the late Miocene-Quaternary Cascade volcanic cover to expose the Eocene Clarno Formation in the Ochoco Mountains. The route east on Highway 26 traverses down section into the Clarno Formation and older units east of Ochoco Summit. **4.0**

4.0 Heading out of town, a series of rim rocks can be seen on either side of the valley. The basaltic rocks on the south side of the valley are late Miocene or Pliocene olivine basalts (Swanson, 1969). The southward-dipping unit just ahead on the north side of the valley is a John Day Formation welded tuff that has laminar flow features similar to rhyolite flows (Swanson, 1969). The late Eocene-early Miocene John Day Formation is sandwiched between the much more resistant Clarno andesites and younger basaltic rocks and crops out poorly in this area. **1.1**

5.1 The road climbs up from the alluvial plain and roughly follows the contact between Clarno Formation andesite flows and southerly dipping late Miocene-Pliocene olivine basalt flows. Pockets of red and white claystones and saprolite occur between the more resistant lava flows and are probably mostly Eocene in age. **2.6**

7.7 The road is now surrounded by Clarno Formation, which consists here of rather fresh andesite flows and minor claystone interbeds (mostly paleosols). **12.7**

20.4 A prominent paleosol developed on flow top breccia is interbedded with andesite flows and is exposed in several roadcuts on the north (left) side of the road. **10.4**

30.8 Road leads to Lucky Strike thunderegg mine on the other side of the Mill Creek Wilderness, where Clarno Formation geodes can be found. Thundereggs are an Honorary Rock by state legislative decree (Lawson, 1989). **0.4**

31.2 At Ochoco Summit, highway 26 crosses from the Deschutes River to the John Day River drainage and into the canyonlands of the John Day Basin. **1.5**

32.7 Andesite dikes cut brecciated andesite flow. **1.0**

33.7 The Ochoco Pass fossil locality is in dark-colored lacustrine shale in the Clarno Formation and intruded by dikes of andesite and veins of calcite. This locality has produced an interesting, if fragmentary, fish assemblage that includes catfishes, bowfins (cf. *Amia* sp.), mooneyes (*Hiodon*) and suckers (cf. *Amyzon*). These lacustrine strata with their overlying, more steeply dipping, gilbert-type bottomset delta beds, are a good example of the bewildering variety of depositional environments encountered in the Clarno Formation. **1.7**

35.4 The two conical buttes south of the road are andesite plugs intruded into Cretaceous marine rocks (Black Butte is the closer and White Butte is distant). They probably represent sub-volcanic stocks of moderate-sized Clarno stratocones. **0.4**

35.8 Marine sedimentary strata of the Cretaceous Gables Creek and Hudspeth formations that have been faulted and folded. This deformation was probably

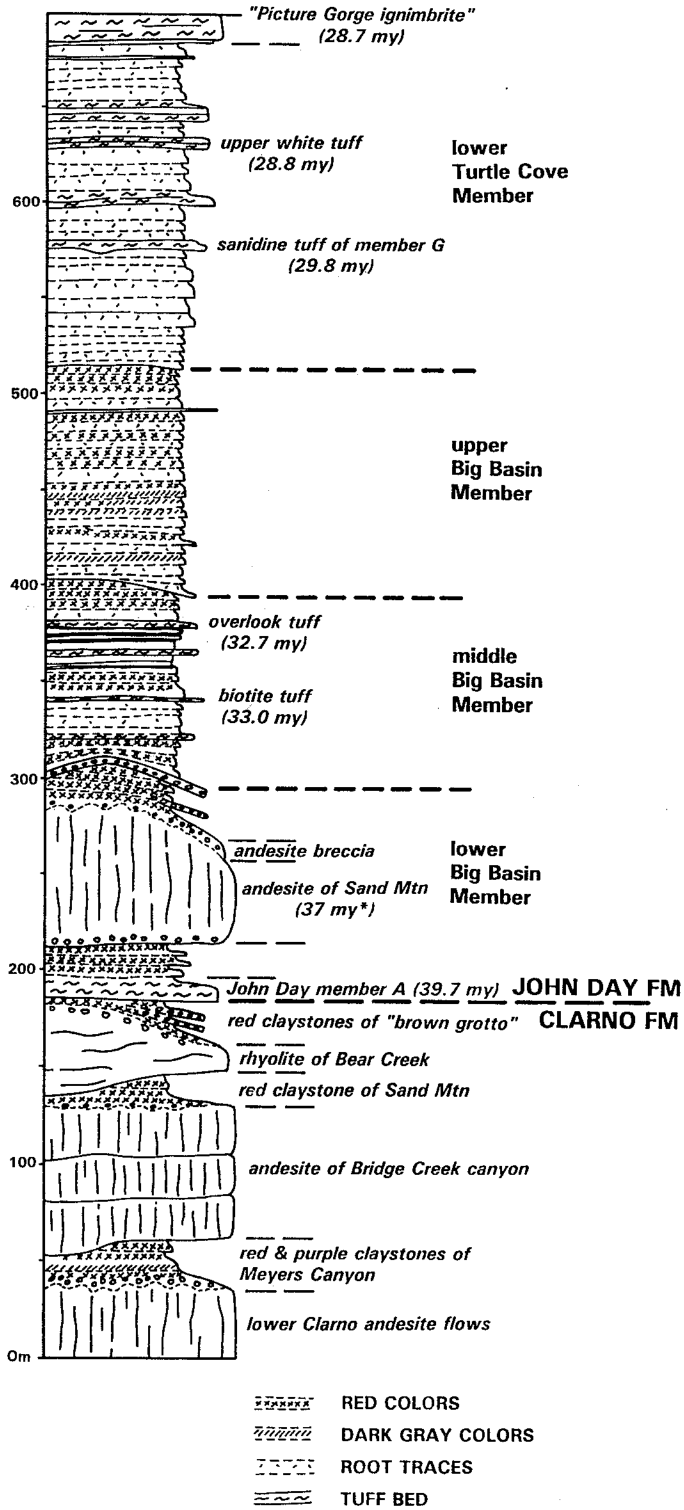

FIGURE 2. Composite stratigraphic section of the upper Clarno and lower John Day formations in the Painted Hills area. Age determination of andesite of Sand Mountain is from Hay (1963) all other age determinations are from Bestland and others (1993).

largely associated with the Mitchell fault, an Oligocene (?) right-lateral strike-slip fault that has approximately 4 km of offset, an east-west orientation, and significant vertical displacement (E. Taylor, pers. commun.). The fault offsets the

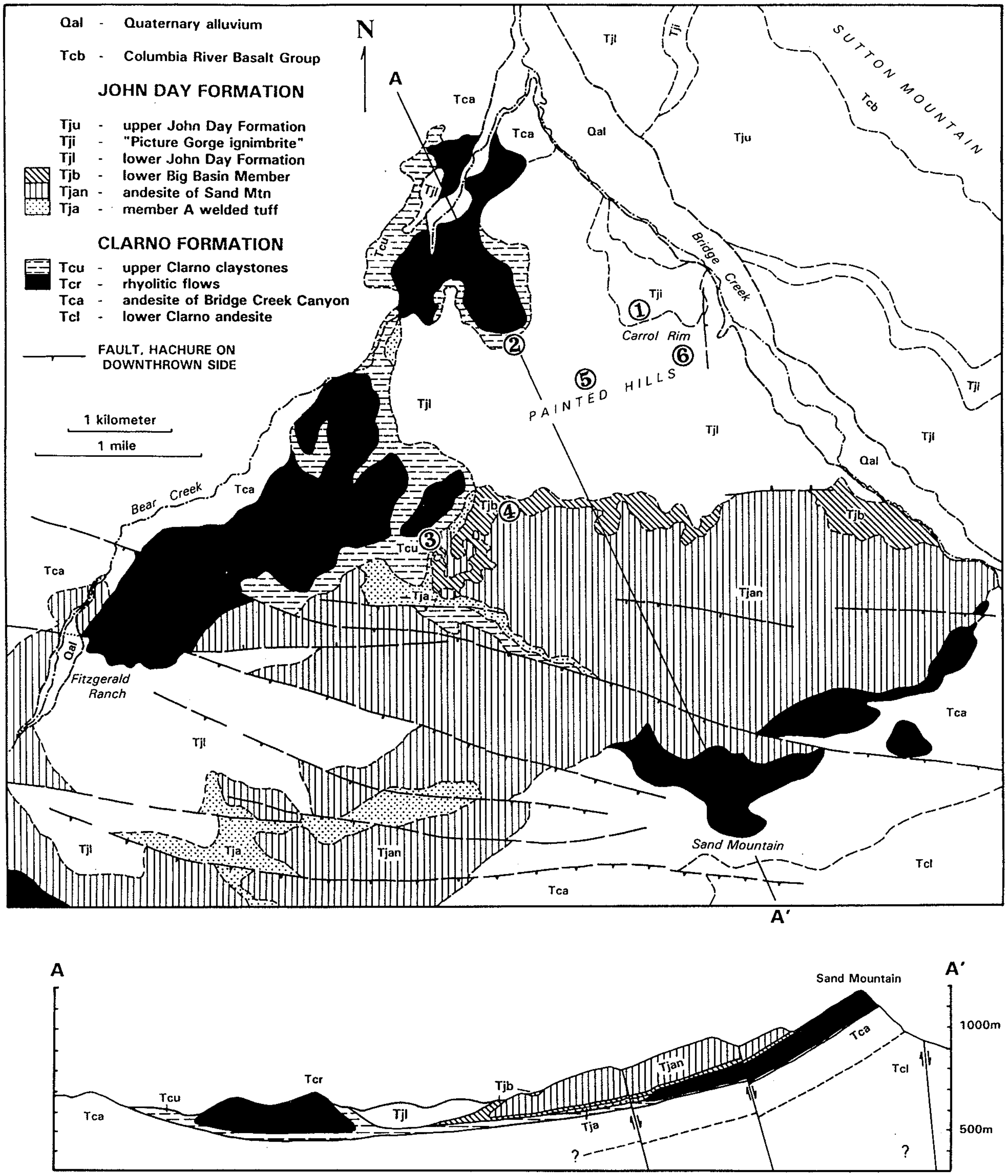

FIGURE 3. Geologic map and cross-section showing the location of field trip stops. Map unit Tjl (lower John Day Formation) contains the middle and upper Big Basin members and the lower Turtle Cove Member.

Mitchell anticline, a northeast-southwest trending fold, also approximately of Oligocene age (John Day units are involved in the folding). **1.0**

36.8 Roadcut of folded and faulted Cretaceous marine rocks probably thrust faulted in association with Mitchell fault (E. Taylor, pers. commun.). **4.5**

41.3 Red outcrops tnorth of the road are well developed paleosols and saprolite zones between Clarno Formation andesite flow units. **2.5**

43.8 South of the highway the Clarno ignimbrite (Oles and Enlows, 1971) forms a local rim-rock and caps a series of indurated paleosol horizons that contain well-preserved, in situ, large tree roots. **0.6**

44.4 Turn left onto the Painted Hills access road and drive up-section through Clarno Formation andesite flows. The Clarno Formation-Cretaceous contact occurs along the main highway, 50 m to the east of this junction. At mile 45.3 in the cliffs west of

Bridge Creek, a sliver of Cretaceous strata is capped by a thick, red ferruginous hardpan. The Cretaceous rocks may occur in a fault sliver but more likely form an erosional remnant onlapped by Clarno andesite flows (E. Taylor, pers. commun.). **1.2**

45.6 An Imperial Mammoth (*Mammuthus imperator*) tusk was collected in the Pleistocene gravels on the west side of Bridge Creek. **0.3**

45.9 The narrows of Bridge Creek canyon is produced by a distinctive, laterally persistent and resistant sequence of pyroxene-plagioclase andesite flows. These andesite flows constitute the base of the lithostratigraphic units mapped during this study and are referred to as the andesite of Bridge Creek canyon (Figs. 2 and 3). Pull off into the Meyers Canyon turnoff and look north toward Sutton Mountain. Clarno Formation andesite flows in the foreground are overlain by John Day Formation tuffs and claystones capped by the Columbia River Basalt Group in the distance. **1.1**

47.0 East of the road (right side) and mostly hidden from view by small hills is "Ruby Basin," where well-exposed paleosol successions of Clarno and John Day age onlap the andesite of Bridge Creek canyon. **0.2**

47.2 Also east of the road is a cluster of prominent red and white banded hills called informally "Barber Pole Hills." These hills contain red claystones, gray claystones (yellow-light gray bands), and tuffaceous claystones (white bands) of the middle and upper Big Basin members. **0.3**

47.5 On the east side of the road is a very local basalt flow within the middle Big Basin Member and of the alkaline, high titania basalt type identified in the western facies (Robinson, 1969; Taylor, 1981). **0.5**

48.0 West of the road, across the valley floor are northerly dipping slopes of a thick andesite unit referred to as the andesite of Sand Mountain. This andesite unit is stratigraphically above the welded tuff of member A and thus within the John Day Formation. This unit will be discussed later in the trip. **0.3**

48.3 Across the valley, red claystones mantle the irregular surface of the andesite of Sand Mountain, producing a complex outcrop pattern. Also visible across the valley are tuffaceous and light-colored John Day Formation units which here have variable dips of up to 25°. Monocline-like folds are responsible for the variable dips and may have been produced by differential compaction of the tuffaceous claystones along the margin of the non-compactable andesite unit.

Along the north side of the road are units of the Oligocene John Day Formation, and toward the skyline is Sutton Mountain and lava flows of the Miocene Columbia River Basalt Group. **0.7**

49.0 Carroll Rim, the prominent cuesta straight ahead down the road, is capped by the "Picture Gorge ignimbrite," a widespread welded ash-flow tuff approximately in the middle of the John Day Formation. This is the top of the section examined during this field trip. **1.1**

50.1 Turn left (southwest) at the intersection of Bear Creek and Burnt Ranch Road into the Painted Hills Unit of the John Day Fossil Beds National Monument. To the northeast are exposures of the upper John Day Formation, including strata lithologically similar to rocks assigned elsewhere to the Kimberly and Haystack Valley members. From these strata below Sutton Mountain were collected some of the first fossils found in the John Day Formation by members of the U.S. Cavalry, later shown to Reverend Thomas Condon, Oregon's first State Geologist. Among the mammals found along the base of Sutton Mountain are large oreodonts (*Promerycochoerus*), giant pig-like omnivores (*Archaeotherium*), and saber-toothed "cats" (family Nimravidae). Drive past picnic area and restrooms left of road. **0.9**

51.0 Behold the Painted Hills. They look best wet with low-angle sunlight from the west. These vividly stripped red, dark blue, and light yellow claystone hills consist almost exclusively of paleosols of the upper Big Basin Member. Look closely for small faults (one a reverse fault) and several small-scale cut-and-fill features (truncation surfaces). **0.3**

51.3 **STOP 1. Painted Hills Overlook and Carroll Rim Hike.** Turn into the overlook parking lot. A 15 minute hike ascends Carroll Rim where the Painted Hills and surrounding area are visible for 360°. First, look eastward at the colorfully banded badland hills of the upper Big Basin Member. These red, black, and yellow claystones are a floodplain paleosol succession; the strata contain few primary alluvial depositional features. The red bands are well-drained Inceptisol to Alfisol-like paleosols that formed under forest or woodland vegetation. The black or dark-blue color in some of the bands is due to Mn-Fe cemented nodules that are present in gleyed, Inceptisol-like paleosols that probably formed under poorly-drained floodplain settings. The yellow bands are weakly developed, Inceptisol-like paleosols.

Along the Carroll Rim trail are large blocks of the "Picture Gorge ignimbrite," a welded ash-flow tuff dated at this locality by C. Swisher at 28.7 ± 0.06 Ma using single crystal, Ar/Ar methods. Looking toward the south from the top of the rim, the resistant hills are all Clarno Formation andesite, rhyodacite and rhyolite flows and lesser amounts of debris flows. To the north, Bridge Creek follows the eastward-dipping contact between the andesite flows of the Clarno Formation and the poorly resistant claystones and tuffs of the John Day Formation. Cuestas of the "Picture Gorge ignimbrite" can be seen downslope from the dark brown cliffs of Sutton Mountain and the Columbia River Basalt Group. To the southwest, just across the small valley, the twin rocky peaks consist of a deeply weathered Clarno-age rhyodacite lava flow. Blood-red and white claystones can be seen mantling this rhyolite body on the southern (left) side of the hill; this is the next stop (Stop 2).

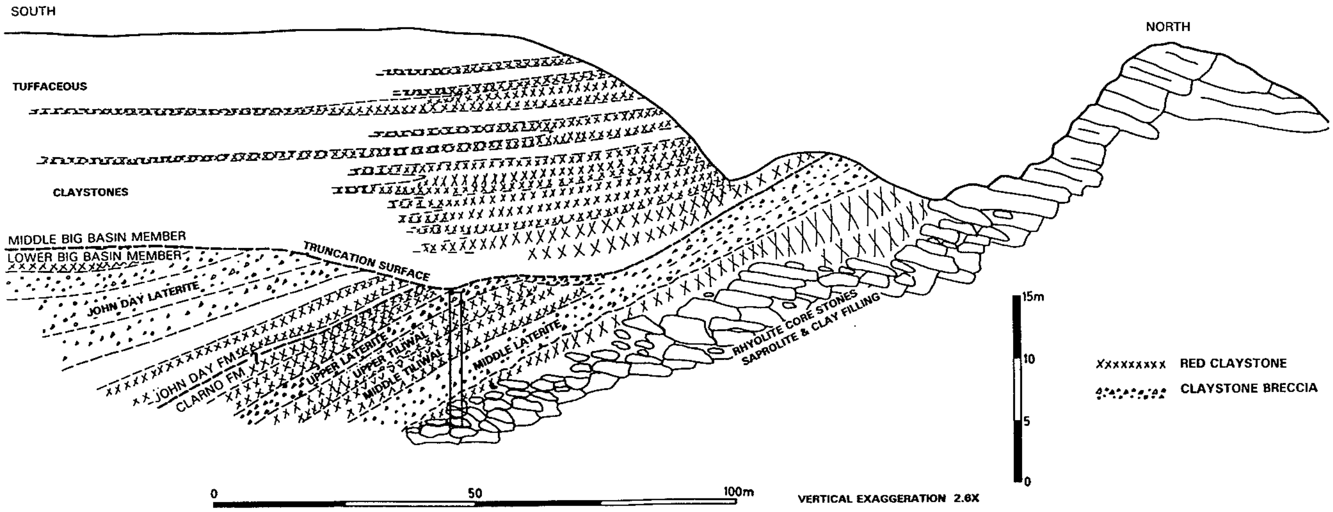

FIGURE 4. Line drawing of "Brown Grotto" looking west from near the road.

Looking southeastward, the juniper-covered ridge trending east-west and directly in front of Sand Mountain consist of a thick andesite flow unit that is within the John Day Formation, but is like Clarno andesite in its composition. The andesite of Sand Mountain will be discussed at stops 3 and 4. The next several stops in the Painted Hills traverse from uppermost Clarno Formation paleosols to paleosols and tuffs just under the "Picture Gorge ignimbrite," spanning about 500 m of section and 14 m.y.

Several geomorphic surfaces can be seen from this vantage point. The surfaces consist of pediments cut into the erodible John Day Formation and armored by andesite cobbles (in areas draining the Clarno Formation) and basaltic cobbles (in areas draining the Columbia River Basalt Group). Two pediment surfaces have been recognized and are separated by approximately 30 m of relief.

Turn left from the overlook parking lot, drive downhill 0.75 mi, and turn left again at the road junction. **1.4**

52.7 **STOP 2. "Brown Grotto."** Park along the road opposite the blood-red and white claystones exposed in the "Brown Grotto" badlands west of the road. Several coarse-grained pedolithic paleosols (deep red-orange resistant horizons) are interbedded with very clayey, light-red horizons in the lower half of this hill (Fig. 4). The upper half of the hill is distinctly different than the lower half and contains Oligocene paleosols of the middle Big Basin Member. Hay (1962) identified a zone of authigenic potassium feldspar replacement of plagioclase in red and yellow claystone strata in the upper part of this hill. A K/Ar date of 22 Ma on this feldspar was interpreted by Hay (1962) to indicate the timing of diagenetic crystallization.

The pedolithic paleosols in the lower part of the hill are detrital laterites in the sense that they have the composition of laterites and are conglomeratic. Mapping indicates that this set of pedolithic paleosols mantles and forms an encircling geometry around the now partly exhumed rhyodacitic flow. The pedolithic paleosols dip away from the lava flow on all sides and truncate underlying paleosols.

The paleosol section begins with a thick saprolite of bleached white, light-red, and purplish-gray kaolinitized rhyodacite. This colorful saprolite can be seen in the rocky slopes uphill. The paleosol horizons overlying the saprolite are extremely weathered. Geochemical mass balance calculations of XRF whole rock data from this section indicate a weathering concentration of up to four times for immobile elements such as Fe^{+3}, Ti, Zr, and Cr when the paleosols are compared to the parent rhyodacite (Bestland and others, 1994). The pedolithic paleosols are significantly more weathered than the mottled, kaolinite-rich paleosols, even though they are coarser grained and retain colluvial depositional features. Given the composition of the Fe-rich clasts and comparisons to modern colluvial Fe-conglomerates, these clasts are interpreted as Fe-cemented soil clasts that were concentrated into layers during periods of downslope colluvial movement and soil erosion. They may represent periods of climatic fluctuation during the late Eocene when the thick soil cover became unstable due to changes in vegetative cover. Each detrital laterite and kaolinite-rich paleosol represents hundreds of thousands of years based on comparison with soils in modern tropical landscapes.

Continue on the road for 1.5 mi, parking by a road junction with a no-camping sign. **1.3**

54.0 **STOP 3. "Red Scar Knoll."** At "Red Scar Knoll," a complex series of stratigraphic relationships are exposed in and around this small red hill including the Clarno-John Day formational contact (Figs. 5 and 6). The welded tuff of member A is exposed here and has been dated from this locality at 39.7 ±

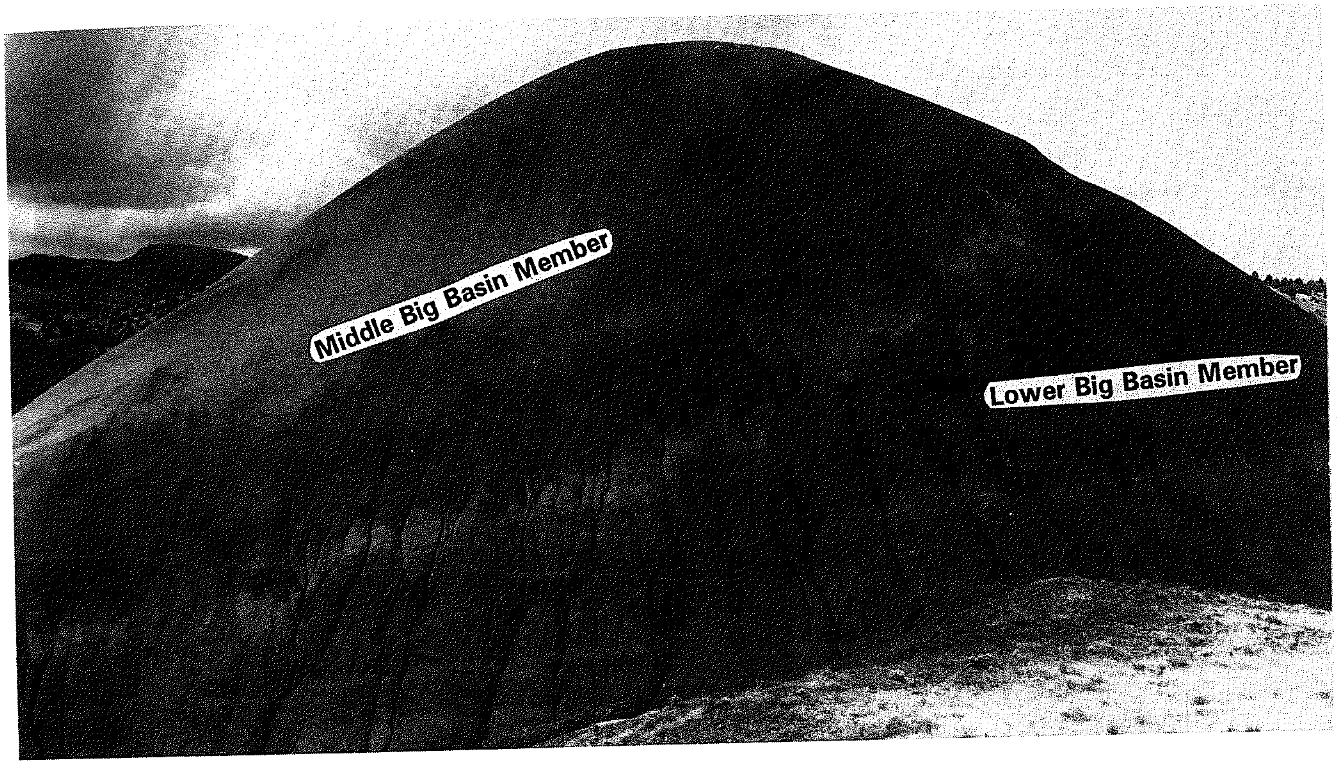

FIGURE 5. The north side of "Red Scar Knoll" showing truncation surface marked by ocher-colored pedolithic horizon which cuts obliquely through hill separating the lower Big Basin Member from the middle Big Basin Member.

0.03 Ma using Ar/Ar methods by C. Swisher (Bestland and others, 1993). Member A was identified here on the basis of lithology including the presence of beta quartz and sanidine crystals and stratigraphic comparison with member A from the western facies of the John Day Formation. Underlying member A are kaolinite-rich, mottled paleosols similar to those at "Brown Grotto" referred to as Tiliwal paleosol types (meaning blood in Sahaptin, Native American language). Directly below member A and overlying a Tiliwal paleosol type is a 1–2–cm–thick carbon-rich horizon that records the vegetation present on the landscape buried by the ash-flow tuff of member A. Just above member A is a distinctive bleached boulder horizon interbedded in deep-red claystones of the lower Big Basin Member. Southeastward and upslope from "Red Scar Knoll," this horizon thickens and grades into weathered andesite flow breccia, andesite saprolite, and fresh andesite of Sand Mountain. The horizon is interpreted as a colluvial deposit on a footslope at the margin of an andesite flow.

On the north side of "Red Scar Knoll," a marked truncation surface separates the lower Big Basin Member from the middle Big Basin Member (Fig. 5). Relatively flat-lying, kaolinite-rich red claystones of the late Eocene lower Big Basin Member are truncated obliquely by a somewhat more resistant claystone breccia horizon (pedolithic paleosol or detrital laterite). Onlapping this horizon are smectite-rich (swelling clay), yellow and reddish-brown paleosols and tuffs of the Oligocene middle Big Basin Member. The difference in the clay minerals between the late Eocene lower part of the hill and the Oligocene upper part of the hill can be seen in their badland weathering characteristics. The Fe- and kaolinite-rich claystones weather to form a more resistant, brick-like profile that erodes into numerous, closely-spaced runnels. The smectite-rich Oligocene claystones and tuffs weather into a "popcorn" soil profile that expands and contracts during wetting and drying and erodes by small-scale mass wasting.

The age of the lower Big Basin Member is bracketed by the 39.7 Ma date on member A tuff at its base, a 37.5 Ma date on the andesite of Sand Mountain (Hay, 1962), which is interbedded with the member, and a date of 33.0 Ma on a tuff near the base of the overlying middle Big Basin Member (Bestland and others, 1993). Thus the Eocene-Oligocene boundary (~34 Ma) is estimated to be above the resistant, pedolithic horizon at the truncation surface and below the smectite-rich claystones.

Drive back down the road and park in the pull-off by the Bridge Creek Flora fossil site. **0.7**

54.7 **STOP 4. "Red Ridge" and Bridge Creek Flora type locality.** The type locality for the Bridge Creek Flora is exposed in the two small hillocks on either side of the road. These tuffaceous brown shales overlie a gleyed paleosol sequence and are capped by a distinctive pumice charcoal tuff. A biotite-tuff dated at 33.0 ± 0.1 Ma by C. Swisher (Bestland and others, 1993) occurs 17 m stratigraphically below the shales in the badlands just east of the fossil site. Over one hundred species have been identified here,

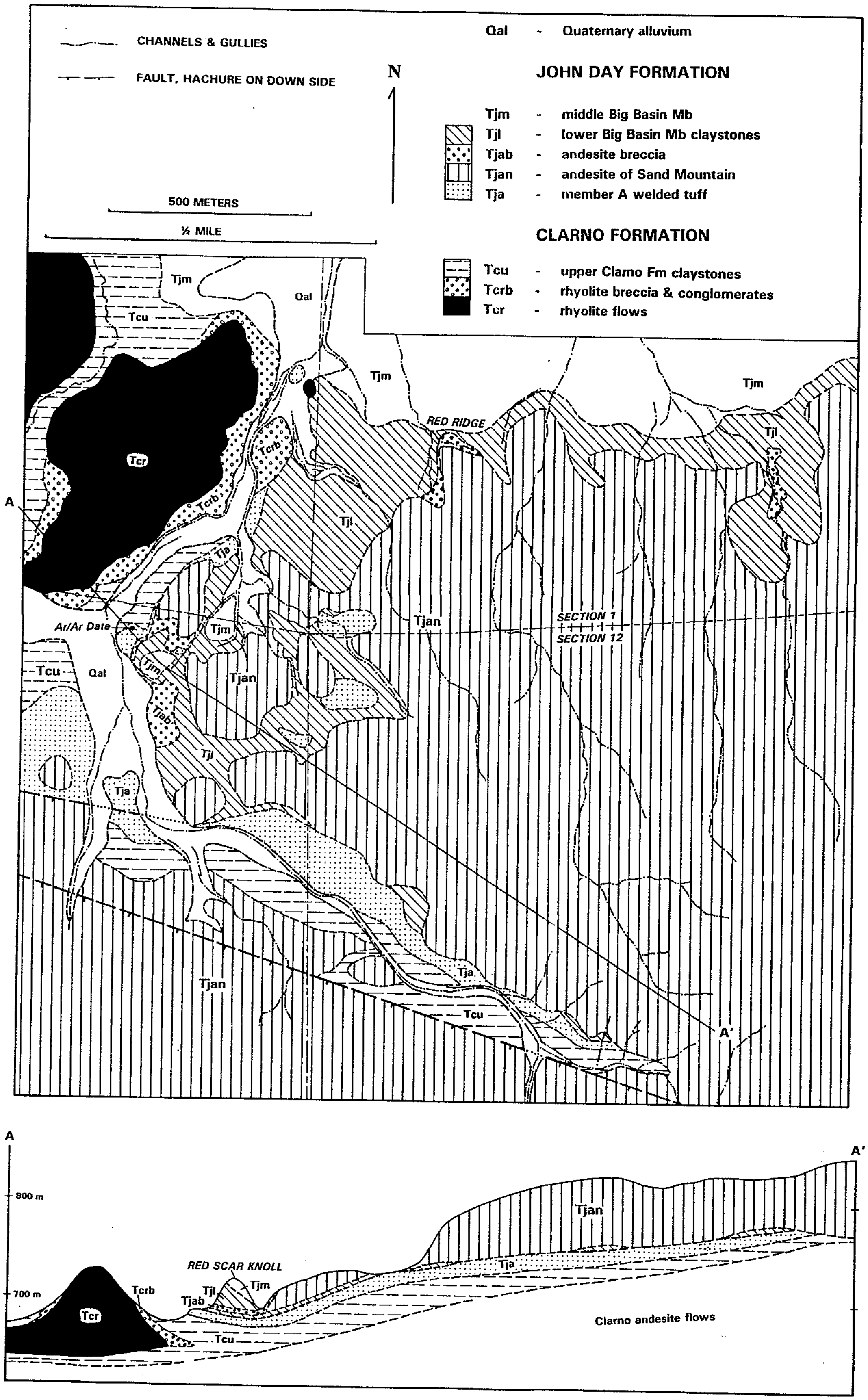

FIGURE 6. Geologic map and cross-section of the "Red Scar Knoll" area, Painted Hills.

FIGURE 7. View of "Red Ridge" showing stratigraphic sequence of bleached andesite saprolite, ocher and red pedolithic horizons, and onlapping smectite-rich claystones of the middle Big Basin Member.

making it one of the most species-rich floras in the Oligocene of North America (Manchester and Meyer, 1987, Meyer and Manchester, in press). This was the first locality to receive a detailed, systematic assessment in an effort to determine paleoclimate (Chaney, 1925). Among the common megafossils found in this locality are maples (*Acer*), elms (*Ulmus*), alders (*Alnus*), "dawn redwood" (*Metasequoia*), and many others. Of considerable interest is the fact that this humid temperate climate flora appears immediately after the Eocene-Oligocene climatic shift. Vertebrate fossils from the John Day lake beds are rare but include salamanders, frogs, fish, and bats.

A short walk east toward a brilliant red hill traverses down section into the lower Big Basin Member (Fig. 7). This member with its Fe- and kaolinite-rich claystones crops out in a strip along the eastern margin of the Painted Hills where it is sandwiched between the middle Big Basin Member and the andesite of Sand Mountain. At "Red Ridge" the gradation from the saprolitic flow breccia to weathered andesite, previously mentioned at "Red Scar Knoll," is nicely exposed. The exposure contains, in ascending stratigraphic order, the andesite of Sand Mountain, andesite flow breccia, kaolinite and Fe-rich claystones, resistant, ocher-colored claystone breccias (pedolithic paleosols), and capping the hill, light-colored, smectite-rich paleosols of the middle Big Basin Member. The onlapping relationship of red claystones onto the flow margin of the andesite of Sand Mountain is clearly visible. The top of the ocher-colored pedolithic paleosols marks a truncation surface, similar to the one just seen at "Red Scar Knoll." A less visible truncation surface truncates these resistant pedolithic paleosols and may approximate the Eocene-Oligocene boundary.

The lower Big Basin Member exposed along the northern margin of the andesite of Sand Mountain is interpreted as a sequence of colluvial soils that accumulated on the toe slope of this large andesite flow unit. These pedolithic paleosols here in the John Day Formation have much the same bulk rock chemistry, textures, and soil features as the detrital laterites from "Brown Grotto," and consequently they are also interpreted to represent colluvial deposition during periods of landscape destabilization and soil erosion.

Return to the parking lot and drive 0.5 mi. to the road junction (55.8), turn right toward the overlook parking lot, and park on the side of the road by a small gully 250 m from the road junction. **1.5**

56.2 **STOP. 5 "Rainbow Hill."** An unmarked trail heads up the gully 50 m and then over an unvegetated flat and on to a long sloping hill. The middle Big Basin Member is exposed in the surrounding hills and records earliest Oligocene alluvial deposition and soil formation based on Ar/Ar dates of 33.0 ± 0.01 Ma and 32.7 ± 0.03 Ma of two tuffs in this member by C. Swisher (Bestland and others, 1993). The middle Big Basin Member contains approximately 91 m of smectite-rich silty claystones that have a few percent of pyrogenic crystals and variable amounts of sand-sized volcanic rock fragments (epiclasts). Lignites and shales occur in the middle of the member and was once mined in this gully. The lignites overlie the distinctive pumice charcoal tuff that overlies the Bridge Creek flora leaf beds of stop 4.

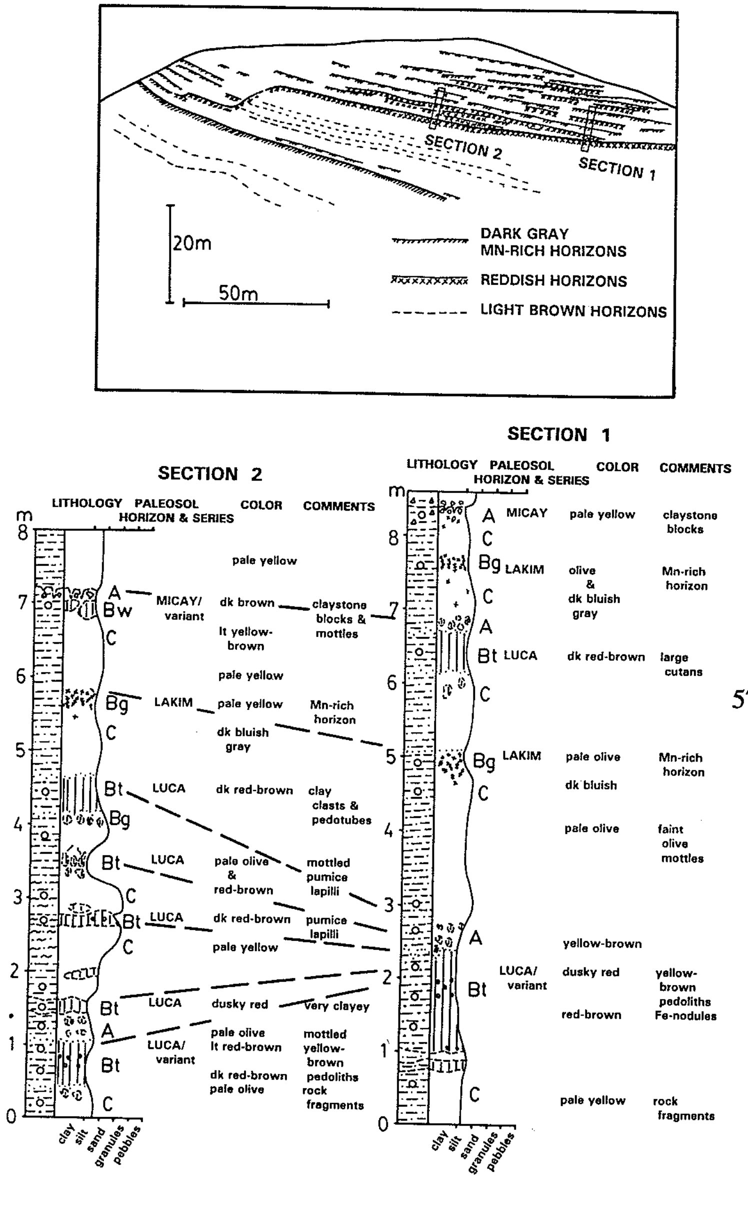

FIGURE 8. Line drawing of the west side of the "Rainbow Hills" with corresponding stratigraphic sections.

The truncation surface that separates the middle and upper Big Basin members, visible in the surrounding hills, is marked by a closely spaced series of thick red claystone horizons. These Alfisol-like paleosols show an up-section increase in the degree of weathering. On the east nose of "Raven Ridge," two aging-upward trends are present in 16 moderate to well-developed paleosols. These red paleosols record a slowing of sedimentation rates during the final stages of middle Big Basin Member deposition.

Approximately 20 m above the boundary between the middle and upper Big Basin members is another truncation surface. This surface is marked by a well-developed red paleosol that truncates underlying yellow horizons on the south side of the Rainbow Hills (Fig. 8). The paleosol on the truncation surface is on-lapped by several red, dark-blue and light-yellow paleosols. The degree of development of the truncation surface paleosol increases up the paleoslope (to the east). In places the paleosol contains a claystone breccia horizon of weakly developed Fe-rich soil clasts (Fig. 8). On the northeast side of "Rainbow Hill," visible from the viewpoint trail, is an additional higher part of this truncation surface, which is separated from the lower section by a short, steep interval. The truncation surface with its steep and gentle slopes is interpreted as terrace risers and treads, respectively. These terraces were produced during episodic downcutting of the floodplain deposits. The terraced landscape was then filled by floodplain alluvium. The higher terraces were exposed to weathering for a longer period of time, and so are covered by better developed soils. The chance for erosion and reworking was also greater for soils on higher terraces and produced the Fe-nodule claystone breccia in parts of this truncation surface.

Return to the road and drive north past the Overlook parking area and down to the flats below Carroll Rim. Pull off on the south side of the road. **0.8**

57.0 **STOP 6. Carroll Rim.** A dramatic change in lithology occurs between the red and clayey Big Basin members of the previous stops and the tuffaceous buff and green lower Turtle Cove Member seen here in Carroll Rim (Fig. 9). Numerous tuffs are present in this section, which is otherwise dominated by weakly developed paleosols, and have yielded dates of 29.8 ± 0.02 Ma (Bestland and others, 1993) for a conspicuous sanidine-rich tuff previously correlated with the western facies member G sanidine tuff by Hay (1963). Another tuff 50 m up-section from the sanidine tuff of member G is the "upper white tuff" dated at this locality by Ar/Ar at 28.8 ± 0.02 Ma (Bestland and others, 1993). Capping the section here is the ash-flow tuff of member H which is informally referred in the eastern facies of the John Day Formation as the "Picture Gorge ignimbrite." Two Ar/Ar dates of 28.7 ± 0.05 Ma and 28.7 ± 0.07 Ma were obtained from this locality. All of these age determinations were by Carl Swisher.

Summary and discussion of the Painted Hills

High precision Ar/Ar age determinations from single crystals in tuffs from the Painted Hills section by C. Swisher allow a preliminary correlation of the stratigraphy with global climatic events (Figure 10). The transition from the Eocene to the Oligocene was a period of profound change in the Earth's climate and biota. The earth changed from the warm, mostly paratropical world of the Mesozoic and Paleocene, to the glaciated world of today (Prothero, 1994). These climatic and biotic changes are centered around the Eocene-Oligocene transition and appear to be stepwise over several million years on either side of the boundary (Zachos and others, 1993). Much of the existing global paleoclimate data come from deep-sea sediments and their oxygen and carbon isotopic record (Keigwin, 1980; Keigwin and Corliss, 1986; Keigwin and Keller, 1984; Miller, 1992) and the eustatic sea level curve of Haq and others (1986). Paleosols are also used

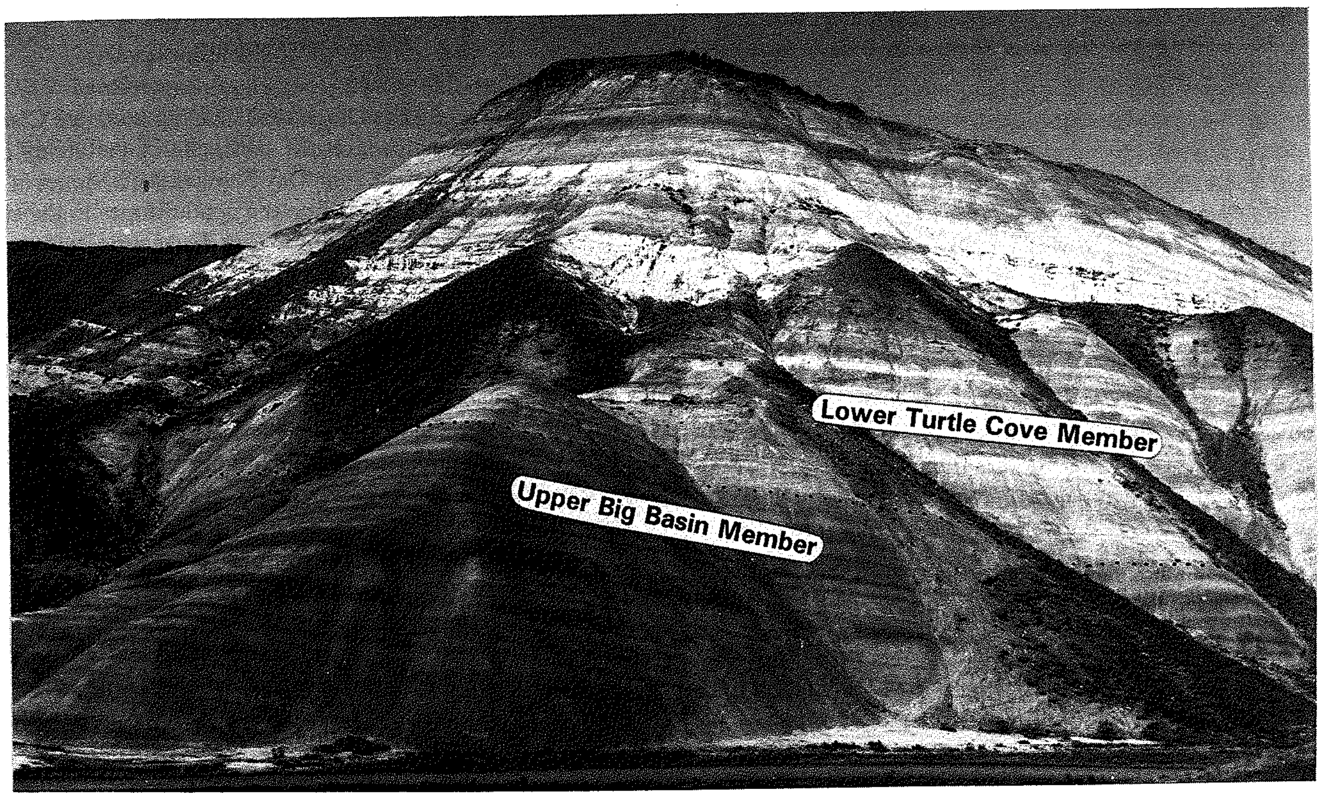

FIGURE 9. The east face of Carroll Rim showing the transition between the upper Big Basin Member and the lower Turtle Cove Member. The "Picture Gorge ignimbrite" caps the butte.

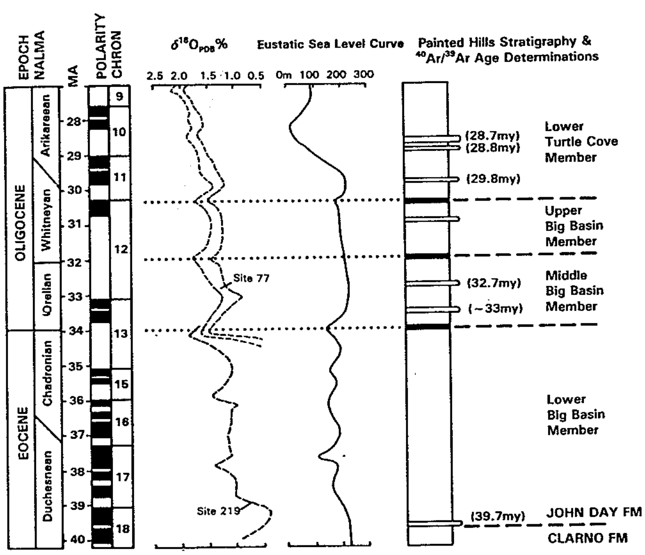

FIGURE 10. Preliminary correlation of the Painted Hills stratigraphy with new time scales and paleomagnetic scales (Cande and Kent, 1992; Swisher and Prothero, 1990) and global climatic events as recorded by isotopic and eustatic sea level curves (Haq and others, 1986; Keigwin, 1980; Keigwin and Corliss, 1986; Zachos and others, 1993).

as evidence of global climate change over this time period (Retallack, 1983; 1990b). Recent work on the timing and global correlation of the Eocene-Oligocene transition has adjusted this boundary to 33.5-34.0 Ma (Swisher and Prothero, 1990; Prothero and Swisher, 1992; Cande and Kent, 1992).

In the Painted Hills area during late Eocene time, low sedimentation rates in a tropical to paratropical climate and the lack of voluminous pyroclastic volcanism allowed extensive lateritic weathering. Floodplain deposition was restricted. Instead iron-and kaolinite-rich paleosols formed on foot slopes of lava flows and other volcanic landforms and were armored by iron-rich conglomeratic hardpans. With the onset of late Eocene Cascade volcanism, represented by the silica-rich, quartz-and sanidine-bearing welded tuff of member A, soils became rejuvenated by additions of pyrogenic ash. The tropical to paratropical climate still inhibited extensive floodplain deposition and created iron-and kaolinite-rich paleosols much the same as during Clarno time. Durable iron-rich conglomeratic paleosols formed on the footslopes of Clarno and John Day lava flows producing the weathered paleosols of the lower Big Basin Member (Fig. 11).

Earliest Oligocene paleosols and alluvial deposits of the middle and upper Big Basin members in the Painted Hills area indicate much higher sedimentation rates and lower weathering rates than during late Eocene time (Fig. 11). The latest Eocene climatic deterioration was a transition from paratropical to humid temperate conditions. Another stepwise climatic change is indicated between the Big Basin Member and the lower Turtle Cove Member based on the degree of weathering of paleosols in these units (Fig. 11). Age determinations in the lower Turtle Cove Member allow for correlation of the boundary between these members with the 30–Ma low stand in sea level from Haq and others (1986) and the 30–Ma spike in the $O^{18/16}$ curve. Both are interpreted as indications of dramatic global cooling and large-scale Antarctic glaciation (Prothero, 1994; Miller, 1992). We interpret the change in paleosol types from the Big Basin Member to the Turtle Cove Member to represent a climatic

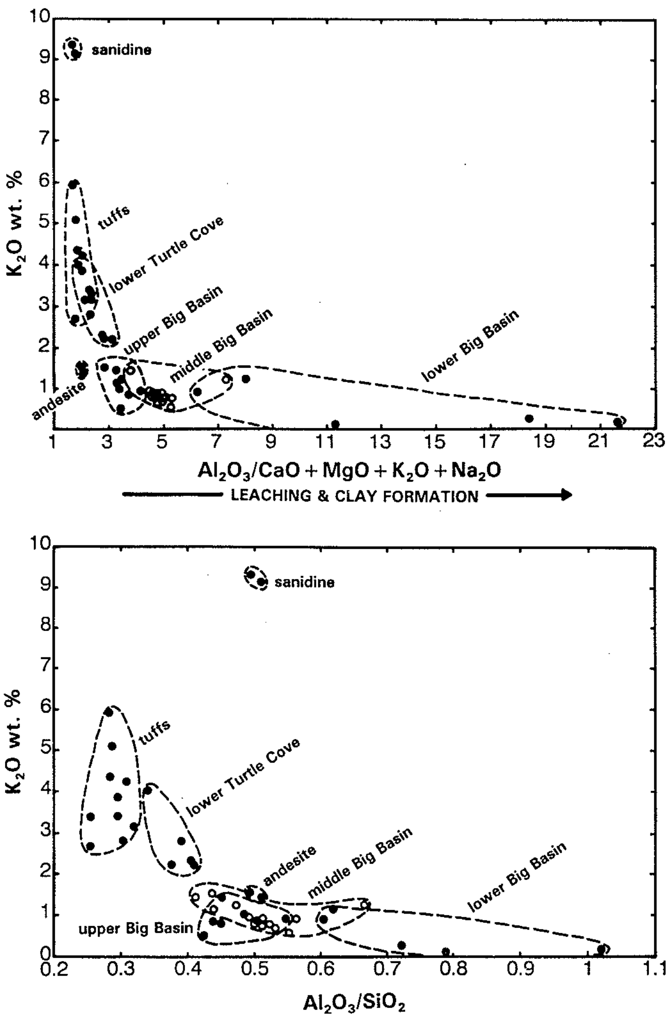

FIGURE 11. Weathering trends of paleosols in lower John Day Formation members from the Painted Hills.

cooling and drying in the Pacific Northwest. The increase in sedimentation rate from the Big Basin to the Turtle Cove is interpreted to correspond to an increase in stream sediment loads and alluvial deposition as a response to drier climate and sparser vegetation.

We have little evidence of tectonic activity in central Oregon during late Eocene and Oligocene times. The lack of fluvial conglomeratic deposits in this part of the Clarno and John Day Formations and the abundance of clayey paleosols indicate broad floodplains with silty, clayey suspended-load river systems. The volcanic input to the basin of ash flow tuff sheets in the western facies of the formation is fairly evenly distributed in time from member A through member I (Woodburne and Robinson, 1977; Robinson and others, 1990). The two most massive ash-flow tuffs in the Painted Hills (John Day members A and H) are both underlain and overlain by very similar kinds of paleosols and conformable with the sequence. Thus neither of these catastrophic volcanic events was the cause of observable downcutting or paleoclimatic change.

Roadlog from Painted Hills to Clarno via Twickenham

58.1 Turn left (north) along Burnt Ranch Road. Along Bridge Creek road heading north are Clarno andesite flows on the west side of the valley and easily erodible John Day Formation claystones in the valley and making up the gentle slopes to the east. Bluffs of upper John Day Formation tuffaceous strata are visible in canyons below the Sutton Mountain cliffs. **1.7**

59.8 The small white mound across the valley to the west is an outlier of member A of the John Day Formation. **0.6**

60.4 The road crosses into Clarno andesite flows. **1.1**

61.5 Take a right turn up the hill just after an abandoned corral. Claystone pockets in the roadcuts are Clarno paleosol interbeds between andesite flows. **0.5**

62.0 The broad bench the road traverses for the next mile marks the Clarno-John Day contact. The "Picture Gorge ignimbrite" and lower Turtle Cove member can be seen in bluffs to the east and indicate that Big Basin members are largely lacking here. **1.7**

63.7 Pass road on left (north) that goes down to the John Day River. **0.3**

64.0 Red and yellow claystones are Clarno Formation paleosols with no fresh pyrogenic material. **1.1**

65.1 **STOP 7. John Day River Overlook.** Pull off to the left (north) onto a track that heads up to a knoll 100 m off the road. Several Clarno Formation lithostratigraphic units can be seen on the north side of the river and dip toward the east. To the northwest is a thick claystone and shale unit with a few lava flow interbeds and fluvial conglomerates. A major cut-and-fill feature is exposed in these badlands in Shaw Canyon; it is better seen on the road that heads west down to the river. To the west, and underlying the claystones in Shaw Canyon, is a thick section of Clarno Formation andesite flows. Overlying the claystones is an extensive andesite unit that makes up the monolith of Red Rock toward the northeast as well as the andesite flows here. The andesite continues into the Rowe Creek valley. Pockets of lower Big Basin Member fill-in low spots on this unit. **2.6**

67.7 Continuing east toward Twickenham, the road traverses up-section from Clarno andesites into the Turtle Cove Member of the John Day Formation. This is the Collins Ranch vertebrate fossil locality, which has yielded *Diceratherium* (a rhino) and oreodonts. **0.8**

68.5 Across the river in the light brown shale is Chaney's Twickenham Bridge Creek flora site. To the north is a prominent ridge capped by the upper cooling unit of the "Picture Gorge ignimbrite." **2.8**

71.3 Turn left onto N. Twickenham road. **2.6**

73.9 The bluffs on the east side of the valley are in the lower Turtle Cove Member. **3.1**

77.0 East-dipping Clarno Formation andesite flows. **0.7**

77.7 Road cut in the welded tuff of member A of the John Day Formation. A road heads west 100 m to a reservoir and a continuation of exposures of member A (Hay, 1963; Robinson, 1975). **0.6**

78.3 Once again into Clarno andesite flows. North from here is a thick section of Clarno Formation andesite flows and debris flows and the axis of the Blue Mountains uplift. **8.6**

86.9 Turn left (west) onto highway 19 toward the town of Fossil. **1.1**

88.0 The road on the left of the highway goes up to Rancheria Rock, a hornblende andesite intrusion with coarse, hornblende phenocrysts. **9.1**

97.1 The town of Fossil is in a valley of easily erodible John Day Formation sandwiched between Clarno andesitic units to the south and Columbia River Basalt Group to the north and west. **0.3**

97.4 Turn left onto highway 218 heading south toward Antelope. Behind Fossil High School on the north side of town is a Bridge Creek Flora leaf fossil site (Manchester and Meyer, 1987). **0.6**

98.0 Roadcut in Clarno Formation andesite flows. **5.0**

103.0 At the summit of this small pass, basalt flows of the Columbia River Basalt Group sit directly on a paleohigh of Clarno andesite units. Distinct stone lines on the grassy hills are characteristic of areas underlain by Columbia River Basalt Group at this elevation. Descending the pass, the road traverses down into a thick section of Clarno Formation. This part of the Clarno Formation contains small intrusions, andesite flows, autobrecciated andesite flows, and coarse volcanic breccia deposits. **7.3**

110.3 In the hoodoo cliffs north of the road is a thick section of andesitic debris flows. These debris flows belong to the upper part of a debris flow unit (conglomerates of Hancock Canyon, Fig. 12) that is exposed for 10 mi along Pine Creek and to the south along the John Day River. **3.6**

113.9 The Clarno Unit of the John Day Fossil Beds National Monument and the Palisades cliffs. Cliffs consists of conglomerates of the Palisades, the lower of the two lahar units in the Pine Creek area (Fig. 12). Preserved at the base of several lahar units is an interesting assemblage of woody debris and occasional forest floor litter of rolled leaves largely of *Joffrea* (katsura) and *Macginitea* (sycamore). **0.6**

114.5 Trailhead that accesses lahar cliffs. Leaf litter is exposed on boulders along the trail. **0.7**

115.2 Turn right onto the Hancock Field Station access road, drive 0.75 mi, park in the lower parking lot, and prepare for a walking tour of at least three hours. **0.8**

116.0 Hancock Field Station is private property within the Clarno Unit of the National Monument, and is run as a natural history camp by the Oregon Museum of Science and Industry in Portland. Inquiries and permission to visit should be obtained from the director (Joseph Jones; 503-763-4691) or other OMSI personnel. Walk west up into camp and then northwest past the A-frame buildings and away from Berrie Hall, a large enclosed dinning hall.

Day 2. Hancock Field Station-Clarno Unit of the John Day Fossil Beds National Monument

meters A footpath leads uphill past the northeastern part of camp. From here field stop numbering starts over at stop 1 and is measured in meters along the trail.

300 m **STOP 1. "Nut beds" overlook, Hancock Field Station.** On the crest of a low ridge is an excellent view of middle to late Eocene alluvial rocks of the Clarno Formation. The prominent bluffs of sandstone and conglomerate are the Clarno "Nut Beds," a well-known fossil locality for leaves, fruit, seeds, wood, and mammals. They are in the upper part of the conglomerates of Hancock Canyon (Figs. 12 and 13). From here the "Nut Beds" can be seen to be lenticular in outline and sandwiched between red claystones on the hill on the skyline and brown, poorly exposed debris flows, tuffs and claystones in the gullies below. The lenticular shape of the "Nut Beds" is obscured somewhat by slumping, especially of the central bluff. These coarse-grained sedimentary rocks represent sandy levees, conglomeratic channels, and lahar run-out of a fluvial system. Some of the paleosols were waterlogged, for example, the gray-green ones below the "Nut Beds" and the two gray bands in the red hillside above. Most of the paleosols, however, were freely drained and have highly oxidized red colors. Blocky outcrops to the northwest at the top of the red badlands are the basal welded tuff of the John Day Formation.

Continue west downhill toward the "Nut Beds" and through the gate in the fence. **350 m**

650 m **STOP 2. Clarno "Nut Beds."** The "Nut Beds" of the Eocene Clarno Formation are interbedded sandstones and siltstones with a cap of massive conglomerate, located 0.5 mi northeast of Camp Hancock. The matrix of the conglomerates includes clay, silt, sand, plant debris—all cemented by multiple generations of chalcedony with local calcite and zeolites. These sediments and their uniquely preserved fossils may have been altered by hot spring activity. The abundant tuffaceous component in the "Nut Beds" is likely to have contributed to silica cementation.

Fossil fruits and seeds, the "nuts" after which these beds are informally named, are found throughout the sequence. Most of the large fruit and seed collection made by the late Thomas Bones (Bones, 1979) came from the basal unit of the upper conglomerate. More recently, Steven Manchester (Manchester, 1981, 1986) has systematically excavated a layer low in the underlying sequence of sandstones and siltstones. A cherty siltstone bed there contains fossil fruits, seeds, leaves, and wood: an uncommon occurrence for a plant fossil locality, offering the promise of allowing reconstruction of complete fossil plants from their different organs. About 100 genera of fruits and seeds, 80 of leaves, and 40 permineralized woods have been recognized in the "Nut Beds" (Bones, 1979; Manchester, 1981, 1986, in press). Common among these are fruits of

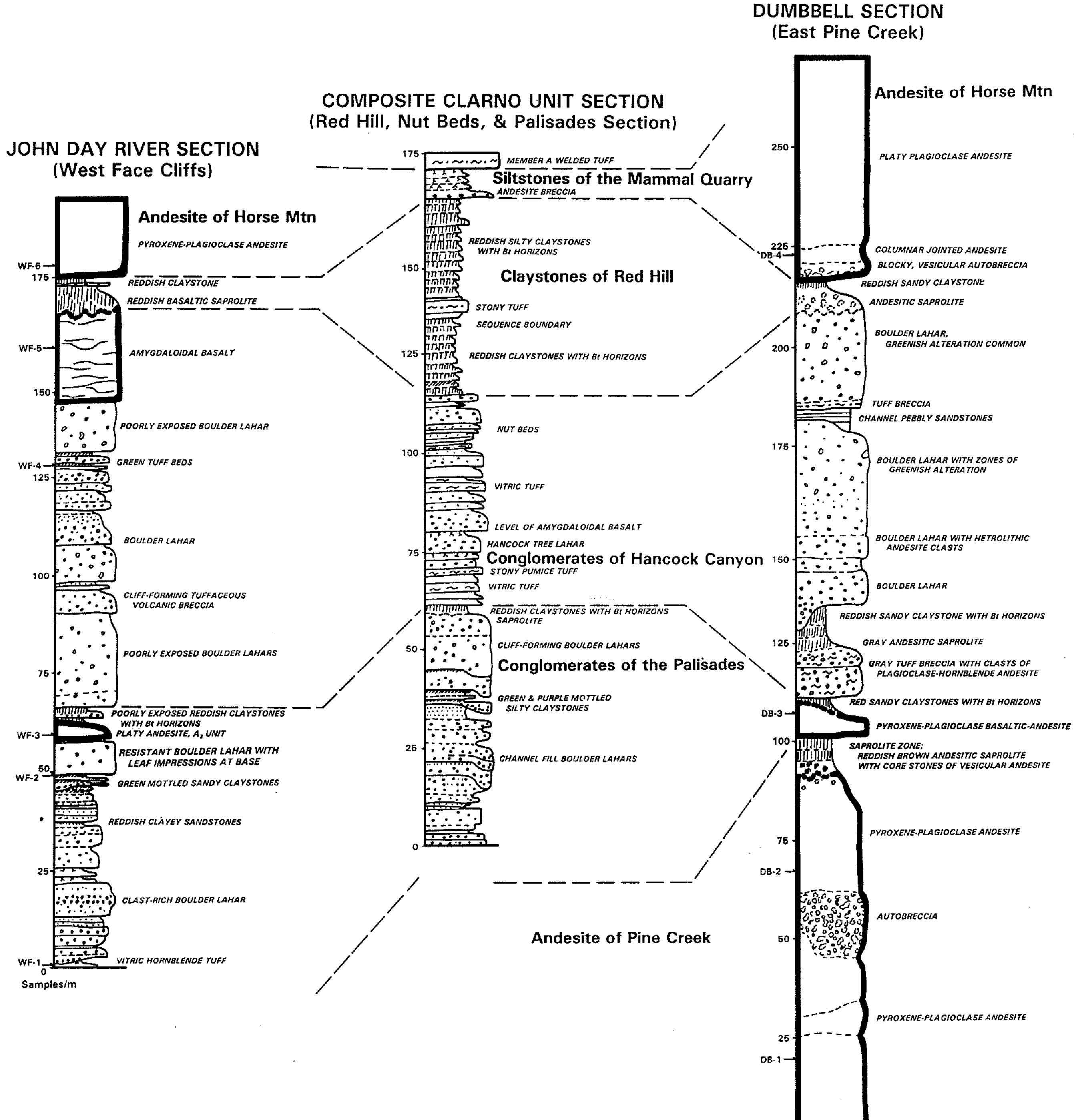

FIGURE 12. Stratigraphic fence diagram of the Clarno Formation in the Pine Creek-Clarno area.

walnuts (*Juglans clarnensis*), moonseed (*Chandlera lacunosa*), icanica vine (*Palaeophytocrene foveolata*), dogwood (*Langtonia*), palm (*Palmocarpon*) and leaves of aguacatilla (*Meliosma*). Modern relatives of most of these plants are restricted to moist, equable tropical regions, such as lowland Panama and Taiwan. In addition, modern relatives of many of the fossils are shrubs, vines and epiphytes, from which it can be inferred that the fossil flora was a community with several tiers such as a rainforest. A warm paleoclimate is indicated for the Clarno "Nut Beds," because many of the leaves are large and most (60 percent) are entire margined.

Fossil mammals have been recovered from the base of the conglomerate in the southernmost outcrop of the "Nut Beds." The fauna includes crocodile, turtle (*Hadrianus*), small browsing horse (*Orohippus major*), small cursorial rhinoceros (*Hyrachyus eximius*), brontothere (*Telmatherium*), and creodont carnivore (*Patriofelis ferox*) (Hanson, 1973;

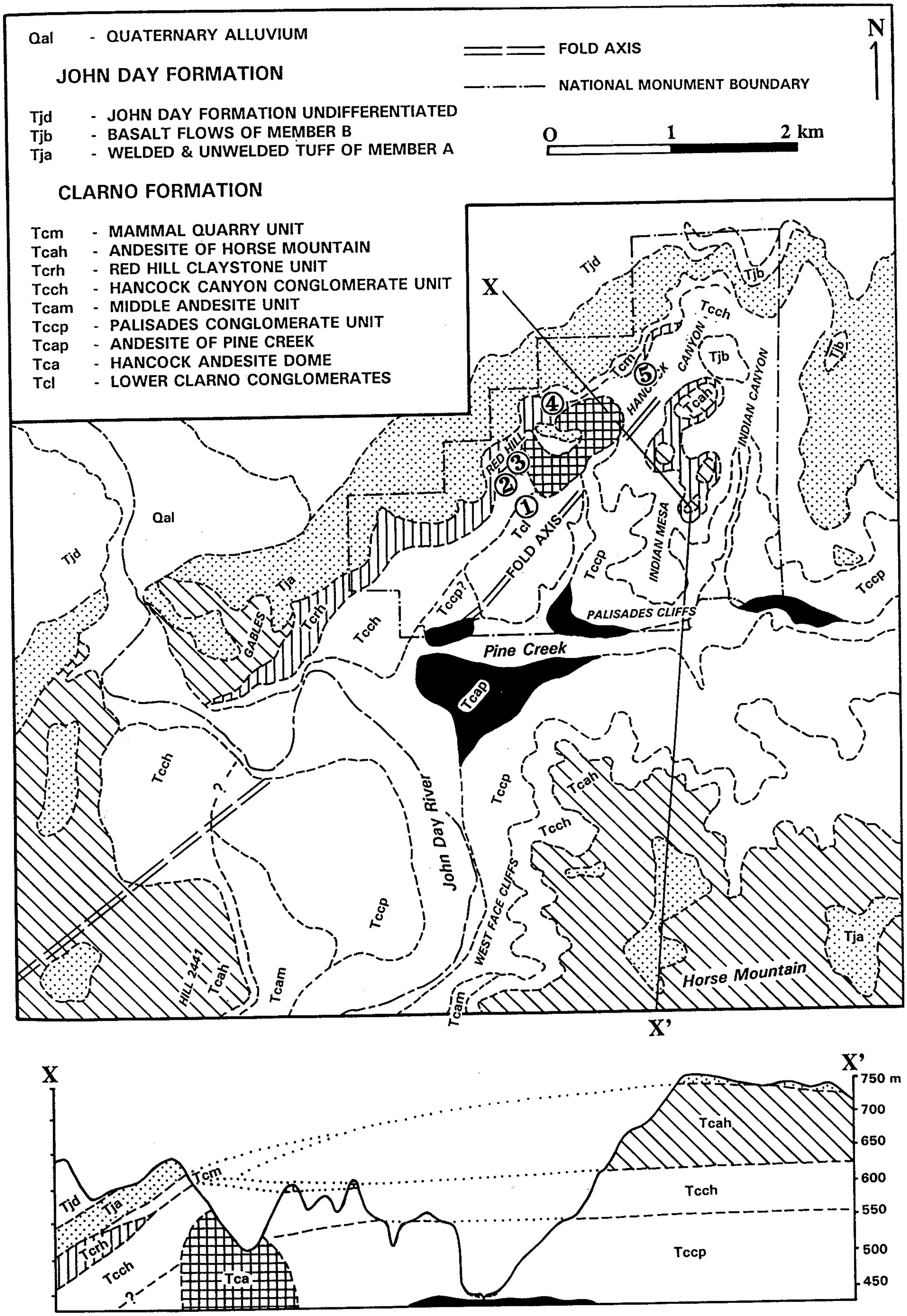

FIGURE 13. Geologic sketch map of the Clarno Unit-Camp Hancock area showing the location of field trip stops.

personal commun., 1990). These creatures are typical of middle Eocene faunas (Bridgerian-Uintan land mammal ages) and of forest communities elsewhere in western North America. A Uintan land mammal age is confirmed by K-Ar estimates of 43.7 and 43.6 Ma for pumice layers in the "Nut Beds" (Vance, 1988) and single crystal Ar/Ar age determinations on plagioclase crystals by C. Swisher of 43.8 Ma.

Continue uphill north from the "Nut Beds" to the right side of the large bowl created by the differential erosion of the resistant "Nut Beds" and the easily erodible red claystones of the Red Hill unit. **150 m**

800 m **STOP 3. "Red Hill."** Red claystones overlying the "Nut Beds" on the hill to the west and north contain numerous strongly developed paleosols of the Eocene Clarno Formation and belong to the claystones of Red Hill (Figs. 12 and 13). The lower part of the hill contains well developed, Ultisol-like paleosols with a brick-red hue (10R). These paleosol profiles have clayey subsurface (Bt) horizons with blocky structure and scattered small (3-4 mm) ferruginous concretions (G.S. Smith, 1988) and are referred to as Lakayx pedotypes (Fig. 14). Gray-colored silty surface horizons are also common, and the greenish-gray color may be due to burial gleization around remnant organic matter. The brick-red color of the subsurface horizons may be in part due to burial dehydration of ferric hydroxides that were originally reddish brown in color. Slickensides along the faces of former soil clods and reduction in thickness due to burial compaction are also present. Such burial alteration is common among paleosols (Retallack, 1990a, 1991c).

The upper, northern part of the red bed sequence consists of less well-developed paleosols (Fig. 14). Above a lithic tuff that is largely covered by red clayey slope wash, the paleosols are still brick-red, but they contain more silt and lack the pervasive clayey structures of the paleosols below and contain less kaolinite and more smectite clay (G.S. Smith, 1988). These are Alfisol-like paleosols. The difference between the upper and lower section of "Red Hill" is apparent in the field and from bulk rock geochemistry of these paleosols (Fig. 14) and may represent a sequence boundary. The difference in paleosol type is interpreted to be due to cooling and drying during late Eocene climatic change. **80 m**

880 m Continue north toward a saddle and the trail. The cliffs and large blocks littering the slope are the basal ash-flow tuff of the John Day Formation. This is probably the material K-Ar dated at 35.7 Ma (from Evernden and James, 1964, corrected by the method of Dalrymple, 1979) and mistakenly thought to be from the Clarno "Nut Beds." Fission track age determinations of 36.8 and 37.4 Ma were made by Vance (1988). More recently, an Ar/Ar age determination of 39.2 ± 0.02 Ma was obtained from this tuff at this locality by C. Swisher (Retallack and others, 1993). This age compares with an age determination

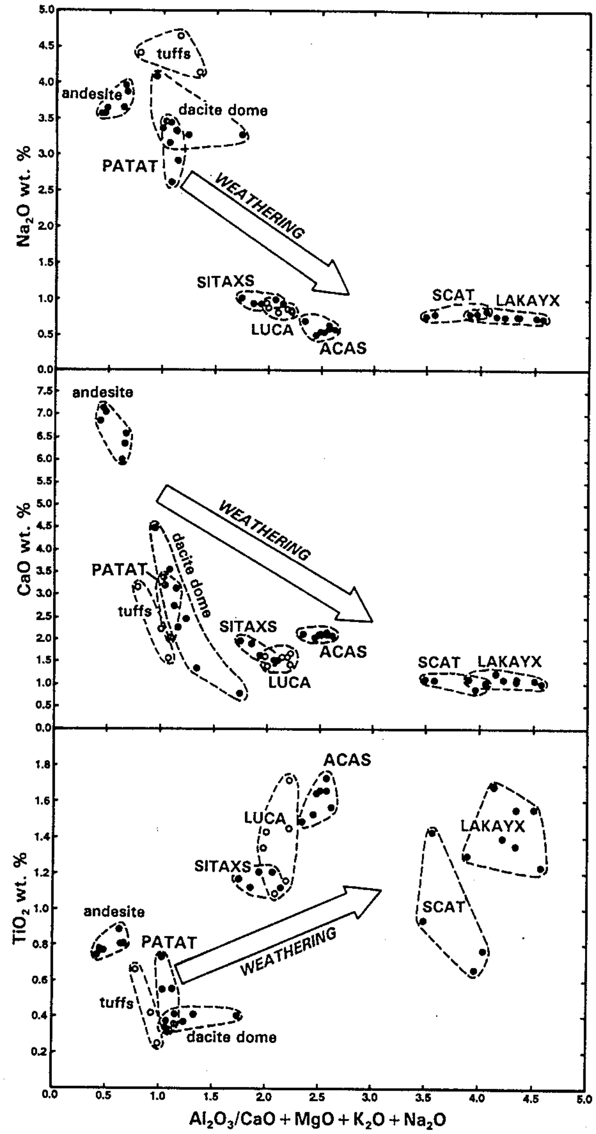

FIGURE 14. Weathering trends of paleosols in the upper Clarno Formation. Sitaxs and Luca pedotypes are from the upper Red Hill sequence and Scat and Lakayx pedotypes are from the lower Red Hill Sequence. Patat pedotype is interbedded with lahars.

of 39.7 Ma for the member A tuff in the Painted Hills, also obtained by C. Swisher. **120 m**

1 km Continue on toward a broad marshy area traversed by a rough jeep track. From the saddle overlooking this area, a flat spur to the east is held up by a basalt flow that is within the upper part of the conglomerates of Hancock Canyon. This flow overlies sediments which in turn overlie the eroded top of a large dacitic intrusion or dome. This hornblende dacite body forms the ridges to the north and east of Camp Hancock (Fig. 13). The conglomerates of Hancock Canyon clearly onlap this igneous body.

This location also offers good views to the north of the basal ash-flow tuff of the John Day Formation on a low ridge to the northeast. Above that are red, then brown and green, then buff or white-colored badlands of the John Day Formation that are below a thick sequence of Columbia River Basalt Group flows exposed in the cliffs of Iron Mountain.

Continue along the jeep trail over a low rise and to a quarry into brown claystones and conglomerates. **600 m**

1.6 km **STOP 4. Clarno "Mammal Quarry."** The "Mammal Quarry" in the upper Clarno Formation is about 1 mi north of the "Nut Beds" (SE¼NE¼ sec. 27, T7S, R19E). These clayey rocks underlie the basal ash-flow tuff of the John Day Formation, but their brown and yellow color contrasts with the brick-red badlands above the "Nut Beds." This sequence is a different alluvial facies that accumulated in response to eruption of a large andesite lava flow unit, the andesite of Horse Mountain (Figs. 12 and 13). The siltstones of the Mammal Quarry were deposited on an erosional landscape developed on top of red beds of the claystones of Red Hill. The floor of the quarry consists of conglomeratic channel deposits with clasts that consist mainly of porphyritic andesite. The walls of the quarry reveal levee deposits of silt and clay with numerous paleosols (Pratt, 1988).

A few fossil fruits and seeds have been found in the paleochannel here (McKee, 1970). These were identified with better-known forms from the nearby Clarno "Nut Beds" and include walnut (*Juglans clarnensis*), moonseed (*Odontocaryoidea nodulosa* and *Diploclisia*), icanica vine (*Palaeophytocrene* cf. *P foveolata*) and grape (*Vitis* and *Tetrastigma*).

Mammal fossils were first discovered here in 1956 by Lon Hancock, and from then until 1959, Hancock, Arnold Shotwell, and Malcolm McKenna developed a large collection of vertebrates, most of it now in the Condon Collection at the University of Oregon. The bones are preserved disarticulated and cracked, within clumps that include few kinds of animals. They appear to have accumulated on the point bar of a stream, as carcasses that rotted and disarticulated in place (Pratt, 1988). Taxonomic work continues on these remains (Hanson, 1973, 1989, personal commun., 1990; Schoch, 1989), which include fish, crocodile (*Pristichampsus*), rodent, anthracothere (*Heptacodon*), rhinoceros (*Teletaceras radinskyi* and *Procadurcodon*), brontothere (*Protitanops*), tapir (*Plesiocolopirus hancocki* and *Protapirus*), agriochoere (*Diplobunops*), horse (*Epihippus gracilis* and *Haplohippus texanus*), creodont carnivore (*Hemipsalodon grandis*), and saber-tooth cat (Nimravinae). These mammals show affinities with Siberian and Chinese faunas. At more than 39 Ma this is the oldest known North American Duchesnean fauna.

Several kinds of paleosols have been recognized in the "Mammal Quarry" above the conglomerate layer (Pratt, 1988). They are thin (20–30 cm), olive- and olive-brown colored, with large root traces and relict bedding (Fluvents). Other paleosols are better developed and contain subsurface zones of clay enrichment (Bt horizons) and silty A horizons with root traces. Such weakly developed paleosols are not compelling evidence for paleoclimate. These paleosols contain large root traces of a size that formed under trees, as well as abundant fine root traces and they probably supported early successional, riparian, woodland. Parent materials of the paleosols were andesitic gravelly alluvium. Each paleosol represents only a few hundred to thousands of years of soil formation.

Walk northeast, contouring below the cliffs of basal ash-flow tuff of the John Day Formation. Continue 650 m into the headwaters of a deep gully with extensive exposures of lahars and into a narrow canyon. The gully to the north contains a section of lahar-runout deposits with a basalt flow interbed that are in the upper part of the conglomerates of Hancock Canyon. A thin red bed above the conglomerates is an eroded remnant of the claystones of Red Hill. **700 m**

2.3 km **STOP 5. Clarno "Hancock Tree."** A lahar rich with wood fragments and leaf impression forms the walls of this small canyon. This lahar is below the basalt flow mentioned above and previously observed at the saddle overlooking the "Mammal Quarry." This basalt flow has been mapped throughout the Clarno Unit of the John Day Fossil Beds National Monument and identified by bulk rock chemistry. The "Hancock tree" is a conspicuous permineralized trunk near the entrance of this small canyon, about 2.5 mi northeast of Camp Hancock. The "tree" (do not deface or sample!) has been identified as similar to the katsura (*Cercidiphyllum japonicum*) of China and Japan. The soil on which it grew is preserved under the lahar, along with its leaf litter (Retallack, 1981). The paleosol is moderately thick (30 cm) and weakly developed (Inceptisol-like), with a light-colored, sandy near-surface horizon (A or E) and an orange, weakly ferruginized, and slightly clayey subsurface horizon (Bw). Its leaf litter includes both leaves and fruits of extinct plants allied to sycamore (*Macginitea angustiloba*) and katsura (*Joffrea speirsii*), plants of cool-temperate climatic and early successional affinities (Crane and Stockey, 1985; Manchester, 1986). The fossil leaf litter also contains a variety of other leaves, including those of fan palms, that today are intolerant of frost. This leaf litter probably represents vegetation early in ecological succession to colonize areas disturbed by lahars and associated floods close to a volcano. The thick lahar (11 m) that overlies the paleosol and leaf litter was preceded by a thin (20 cm) traction deposit, similar to those attributed to hyperconcentrated flows associated with lahars (Smith, 1986b; Nemec and Muszynski, 1982). Neither this flood of water nor the lahar itself succeeded in dislodging all the trees. The deposit probably compares with the somewhat passive floodplain-facies lahars of Scott (1988).

Continue down the gully past the "Hancock tree" and into the main valley of Hancock Canyon. A footpath follows the dry creek bed south toward Hancock Field Station and past a small stock pond. **700 m**

3.0 km In the hillocks north of the stream are exposures of the hornblende dacite body.

Continue south along the foot trail into Hancock Field Station and the vehicles. This is the conclusion of the walking tour. Head out to Oregon Hwy 218 and proceed west to Antelope.

Acknowledgments

We thank R.L. Hay and D.A. Swanson for reviews. Conversation and field consultations with Paul Hammond, Allan Kays, Edward Taylor, John Dilles, Dave Blackwell and John Stimac have added to our understanding of the geology of north-central Oregon. The geologic and stratigraphic work presented here was largely done by E. Bestland and G. Retallack under contract number CX-9000-1-0009 with the National Park Service from 1991-1994.

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