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Cover photo

The Palisades, a prominent cliff in the Clarno Unit of the John Day Fossil Beds National Monument, formed by the erosion of massive debris-flow deposits. Article beginning on next page describes the geology of this region. Photo courtesy of Erick A. Bestland.

Mount Hood earthquake swarm of January 1999

During the month of January, Mount Hood experienced an earthquake swarm similar to past events. This swarm produced 81 recorded events, including 4 events between magnitude 3.0 and 3.2. Events were felt at Timberline, Brightwood, Parkdale, and Mount Hood Meadows. The majority of events (41) occurred on Monday, January 11, followed by 9 events on January 12, 1 event on January 13, 18 events on January 14, and 12 events on January 15. The earthquakes were focused approximately 6 km to the south-southeast of the summit of Mount Hood, with hypocenter depths ranging from 1.1 to 9.4 km below the surface. In the last decade, 15 other similar swarms have been located in approximately the same area, and the largest recorded earthquake was a magnitude 4.0 event in December 1974.

The location and concentration of earthquake swarms in this specific area is believed to indicate a northwest-trending fault that is in line with the overall regional tectonic stresses. Fault plane analysis of the largest event (magnitude 3.2 on January 11) indicates normal faulting.

Mount Hood is considered an active volcano with the potential for damaging earthquakes, eruptions, dome collapses, pyroclastic flows, lahars, debris flows, and jökulhlaups (glacial outburst floods). Current activity includes earthquake swarms and small fumaroles in the Crater Rock area. The last eruptive phase was the Old Maid Flat event occurring between 200 and 300 years ago, although individual reports in 1859, 1865, and 1907 mention small localized ash, pumice, and steam events. The valleys of the Hood and Sandy Rivers are built largely on eruptive and debris material from Mount Hood.

Recent swarm earthquakes with magnitude ≥2.5

Date	Time	Lat (N)	Long (W)	Depth (mi)	Magnitude	Location quality	Distance SSE of Mount Hood (km)
99/01/11	13:48:46	45.31	121.65	7.5	2.5	CB	6.5
99/01/11	16:54:11	45.31	121.65	7.2	3.0	CB	6.5
99/01/11	22:04:14	45.31	121.65	6.8	3.2	BB	7.0
99/01/14	11:56:47	45.31	121.66	7.6	3.2	CB	5.4
99/01/14	16:13:42	45.31	121.65	5.9	3.0	BB	6.2

For more information, visit the websites of the U.S. Geological Survey Cascades Volcano Observatory: http://vulcan.wr.usgs.gov/Volcanoes/Hood/framework.html; and the University of Washington Geophysics Program: http://www.geophys.washington.edu/SEIS/PNSN/HOOD/

Geologic framework of the Clarno Unit, John Day Fossil Beds National Monument, central Oregon

by E.A. Bestland[1], P.E. Hammond[2], D.L.S. Blackwell[1], M.A. Kays[1], G.J. Retallack[1], and J. Stimac[1]

ABSTRACT

Two major geologic events are recorded in the Eocene-Oligocene volcaniclastic strata, volcanic flows, and paleosols of the Clarno Unit of the John Day Fossil Beds National Monument. A major plate-tectonic reorganization in the Pacific Northwest at about 40–42 Ma shifted volcanism from the Clarno volcanic province, represented by Clarno Formation andesitic flows and debris flows, to the Cascade arc, represented by John Day Formation tuffaceous deposits and ash-flow tuffs. Evidence of the second major geologic event comes from paleosols and fossil remains of plants and animals in these two formations and indicates a global paleoclimate change centered around the 34-Ma Eocene-Oligocene boundary, when the earth changed from a tropical Eocene "hothouse" to a temperate Oligocene "icehouse."

In the Clarno Unit area, the lower part of the Clarno Formation consists of structurally domed debris-flow conglomerates, andesite flows (51.2 ± 0.5 Ma), and a dacite dome (53.5 ± 0.3 Ma), both onlapped by less deformed debris-flow conglomerates, andesite flows (43.4 ± 0.4 Ma), and red beds. The onlapping conglomerates are composed of two widespread units that are dominated by debris flows, are separated by red claystones (paleosols), and are each approximately 60 m thick. The lower unit, conglomerate of The Palisades, consists of channel and floodplain debris-flow conglomerates and lahar runout deposits. The overlying conglomerates of Hancock Canyon also contain channel and floodplain debris-flow conglomerates but have, in addition, fluvially reworked conglomerates, reworked tuff beds, a distinctive amygdaloidal basalt flow (43.8 ± 0.5 Ma), and the fossil site known as the "Nut Beds." Both units accumulated on volcanic aprons in response to volcanism (synvolcanic sedimentation) in an area of irregular topography, including hills of a preexisting dacite dome.

Above the conglomerates are thick but discontinuous red claystones (claystone of Red Hill), which record a long period of volcanic quiescence (2–4 m.y.), slow floodplain aggradation, and long periods of soil formation. The Red Hill paleosols and fossil plants from the Nut Beds, which directly underlie the red beds, are evidence of a climate that was subtropical and humid. Disconformably overlying the red beds are gray-brown siltstones and conglomerates of the Hancock Mammal Quarry, which have yielded a titanothere-dominated fossil fauna (Duchesnean North American Land Mammal Age).

The Clarno Formation is overlain abruptly by an ash-flow tuff of the basal John Day Formation (39.2 ± 0.03 Ma). A major lithologic boundary occurs in the lower John Day Formation between kaolinite- and iron-rich claystones (paleosols) of the lower Big Basin Member (upper Eocene) and smectite and tuffaceous claystones of the middle Big Basin Member (lower Oligocene). An age determination of 38.2 ± 0.07 Ma on a tuff in the lower Big Basin Member and a 33.6 ± 0.19 Ma age determination for the Slanting Leaf Beds in the middle Big Basin Member support the interpretation that the contact between these two members is close to the Eocene-Oligocene boundary. These fossil leaf beds are thus earliest Oligocene in age, similar in age to the type locality of the Bridge Creek flora in the Painted Hills area.

INTRODUCTION

The scenic high desert of north-central Oregon contains a colorful volcanic and alluvial sequence of Tertiary age (Figure 1). For the protection and appreciation of the geologic and paleontologic resources in this area, three "Units" (Sheep Rock, Clarno, and Painted Hills) were established in the John Day Fossil Beds National Monument. The strata exposed in the National Monument record two important geologic events: (1) The change from Eocene Clarno arc volcanism, represented by the Clarno Formation, to late Eocene Cascade arc volcanism and John Day Formation back-arc deposition is recorded in these two formations. (2) A dramatic paleoclimatic change occurred across the Eocene-Oligocene transition during which conditions changed in central Oregon from subtropical humid to semiarid temperate climate. The magnitude and timing of these paleoclimatic changes as well as the stratigraphic positions and ages of fossil sites have been worked out from detailed mapping and section-measuring in the Clarno Unit area of paleosols (ancient soils), fossiliferous beds, and radiometrically dated tuff beds. This mapping has also revealed a domal volcanic edifice of Clarno age that was emplaced early in the accumulation of the formation and was subsequently onlapped by volcaniclastic deposits.

The purpose of this paper is to provide a geologic and paleoenvironmental summary of the Clarno and lower John Day Formations in the Clarno Unit area of the John Day Fossil Beds National Monument. This

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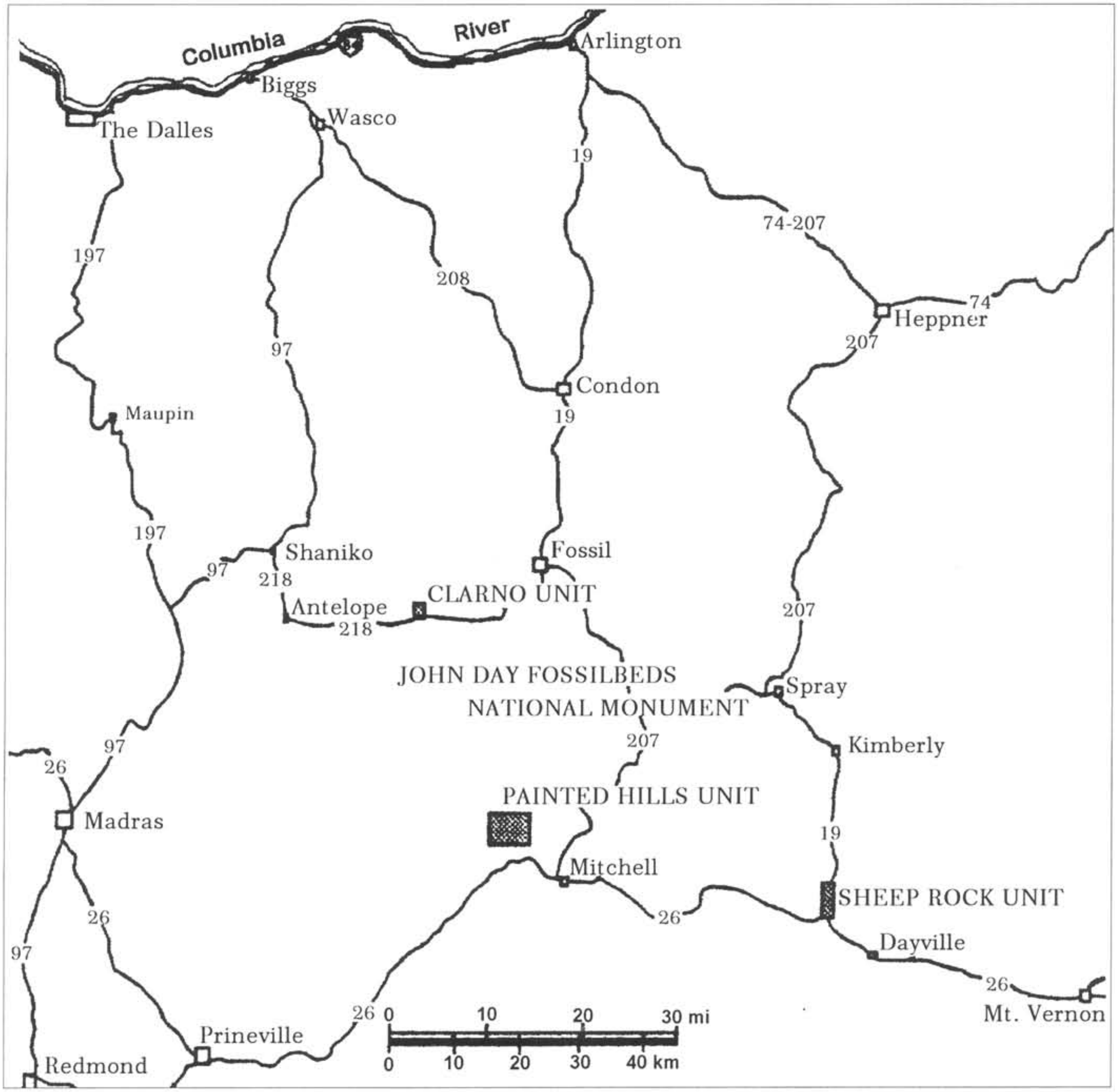


Figure 1. Location map of north-central Oregon showing units of the John Day Fossil Beds National Monument and major access roads.

paper represents a synthesis of the combined efforts of three different groups that have worked extensively in the Clarno area. A three-year study by Bestland and Retallack for the National Park Service generated an extensive and detailed data base of mapping, volcanic and paleosol stratigraphy, new $^{40}Ar/^{39}Ar$ age determinations, and discovery of new fossil sites (Bestland and Retallack, 1994a). The University of Oregon Field Camp has been mapping in this area since 1985 and is developing a regional map of the Clarno and John Day Formations along the north side of the Blue Mountains uplift. Portland State University Geologic Field Methods students and staff have been mapping in this area since 1988 and have concentrated on detailed lithostratigraphic mapping of the National Monument.

The informal stratigraphic subdivisions of the Clarno and John Day Formations presented here are based on rock type and stratigraphic position (Figures 2 and 3). New stratigraphic units identified are all informal in accordance with rules about such units in the North American Commission on Stratigraphic Nomenclature (1983). The new subdivisions will be denoted by lower case such as "lower Big Basin Member."

GEOLOGIC SETTING

Clarno Formation

The Clarno Formation is a thick section (up to 6,000 ft [1,800 m]) of largely andesitic volcanic and volcaniclastic rocks of Eocene age that crops out over a large area of north-central Oregon. The formation was named by Merriam (1901a,b) for exposures of volcanic rocks at Clarno's Ferry, now a bridge over the John Day River west of the National Monument boundary. The Clarno Formation disconformably overlies pre-Tertiary rocks that include highly deformed metasediments of Permian to Triassic age (Hotz and others, 1977), Cretaceous marine rocks in the Mitchell area and sedimentary rocks of uncertain age mapped as Cretaceous sedimentary rocks by Swanson (1969) and interpreted as Paleocene or Eocene sedimentary equivalents of the Herren Formation (Wareham, 1986; Fisk and Fritts, 1987). The formation is overlain for the most part by the John Day Formation. Where the formation formed ancient volcanic highlands, younger rock units such as the Miocene Columbia River Basalt Group, Miocene Mascall Formation, Miocene-Pliocene Rattlesnake Formation, and Miocene-Pliocene Deschutes Formation, disconformably overlie the Clarno Formation.

The Clarno Formation consists of nonmarine volcanic and volcaniclastic units that range in age from middle to late Eocene, some 54 to 39 m.y. old (Evernden and James, 1964; Evernden and others, 1964; McKee, 1970; Enlows and Parker, 1972; Rogers and Novitsky-Evans, 1977; Manchester, 1981, 1990, 1994; Fiebelkorn and others, 1982; Vance, 1988; Walker and Robinson, 1990; Bestland and others, 1997). Volcanic plugs, lava flows, and lahars, with convergent-margin andesitic compositions and textures, indicate accumulation in and around andesitic volcanic cones (Waters and others, 1951; Taylor, 1960; Noblett, 1981; Suayah and

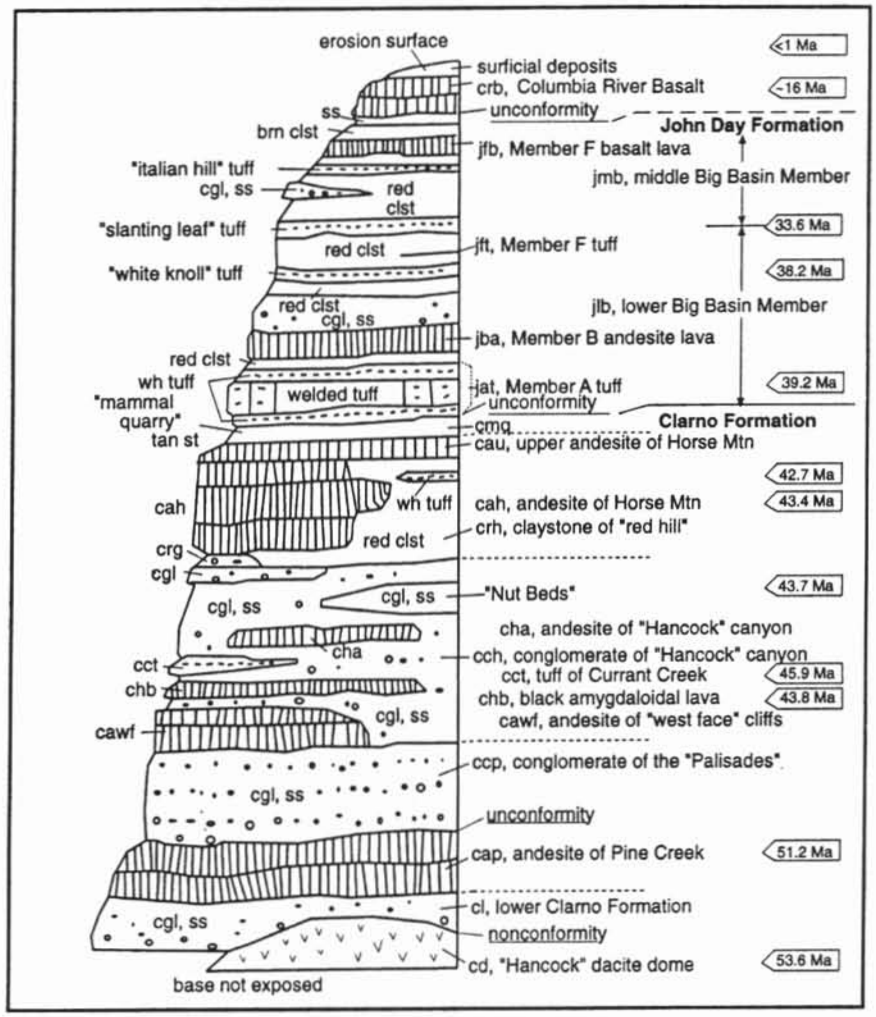


Figure 2. Composite stratigraphic section of the upper Clarno and lower John Day Formations in the Clarno Unit of the John Day Fossil Beds National Monument. Diagram shows informally recognized stratigraphic units and corresponding age determinations. For explanation of symbols to units, see geologic map of Figure 3. Additional symbols are: brn (brown); cgl (conglomerate); clst (claystone); ss (sandstone); st (siltstone); and wh (white).

Rogers, 1991; White and Robinson, 1992; Bestland and others, 1995). The calc-alkaline volcanic rocks represent subduction-related andesitic volcanism, probably on thin continental crust (Rogers and Novitsky-Evans, 1977; Rogers and Ragland, 1980; Noblett, 1981; Suayah and Rogers, 1991). White and Robinson (1992) evaluated the sedimentology of the volcaniclastic deposits on a regional scale and interpreted the strata as nonmarine volcanogenic deposits that were deposited in alluvial aprons and braidplains that flanked active volcanoes.

John Day Formation

The John Day Formation consists of rhyolitic ash-flow tuff and dacitic to rhyodacitic tuffs and alluvial deposits of latest Eocene, Oligocene, and early Miocene (39–18 m.y.) age (Woodburne and Robinson, 1977; Robinson and others, 1990; Bestland, 1997; Bestland and others, 1997). Robinson and others (1984) interpret these primary pyroclastic, alluvial and lacustrine deposits as the distal deposits from vents to the west in the Western Cascades and from more proximal vents now buried or partially buried by the High Cascade volcanic cover.

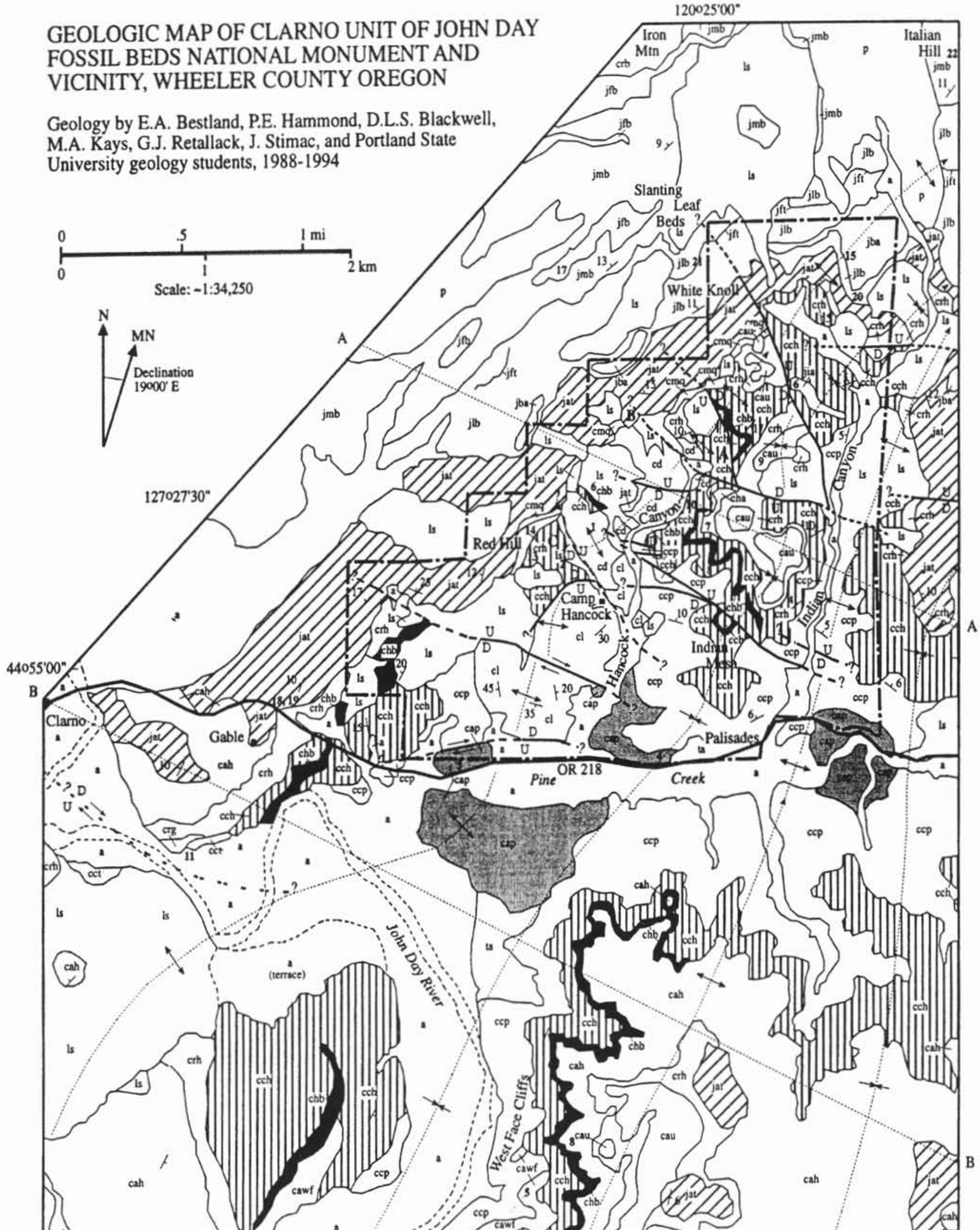


Figure 3. Informal geologic map of the Clarno Unit of the John Day Fossil Beds National Monument and vicinity (modified from Bestland and Retallack, 1994a; unpublished mapping by P.E. Hammond and Portland State University students; and unpublished mapping by M.A. Kays, D.L.S. Blackwell, J. Stimac, and E.A. Bestland).

EXPLANATION

Rock units are symbolized here and on the map without the usual period designation: in this case, "Q" for some Quaternary surficial units and "T" for all other, Tertiary, units.

Surficial deposits

a	Alluvium
ls	Landslide
ta	Talus
p	Pediment

Bedrock units

crb	Columbia River Basalt Group

John Day Formation

jmb	Middle and upper Big Basin members
jfb	Member F basalts
jlb	Lower Big Basin Member claystones
jft	White tuff of member F
jba	Member B basaltic andesite
jat	Welded tuff of member A

Clarno Formation

cmq	Siltstone of Hancock Mammal Quarry
cah	Andesite of Horse Mountain
cau	Upper andesite of Horse Mountain
crh	Claystone of Red Hill
cha	Andesite of Hancock Canyon
crg	Conglomerate
cct	Tuff of Currant Creek
chb	Basalt of Hancock Canyon
cch	Conglomerate of Hancock Canyon
cawf	Andesite of West Face Cliffs
ccp	Conglomerate of The Palisades
cap	Andesite of Pine Creek
cl	Lower Clarno Formation
cd	Hancock dacite dome

Contact

Indefinite contact

45 Strike and dip of bedding

Fault, showing displacement; U=upthrown side, D=downthrown side

Indefinite fault

Fold axis, showing plunge

Anticline

Syncline

Thus, the transition between the Clarno and John Day Formations records 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 John Day Formation is divided into eastern, western, and southern facies on the basis of geography and lithology (Woodburne and Robinson, 1977; Robinson and others, 1984). The Blue Mountains uplift separates the western and eastern facies; it also restricted deposition of much of the coarser grained pyroclastic material to the western facies.

The western facies is informally divided into members A through I on the basis of laterally extensive ash-flow tuffs sheets (Peck, 1964; Swanson and Robinson, 1968; Swanson, 1969). This 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 of member F. The Clarno Unit area is in the western facies, where the John Day Formation has been mapped in reconnaissance style by Robinson (1975), who used the stratigraphic divisions of members A through I.

The eastern facies is divided into four formal members (Fisher and Rensberger 1972). From bottom to top they are Big Basin Member (red claystones), Turtle Cove Member (green and buff tuffaceous claystones), Kimberly Member (massive tuff beds), and Haystack Valley Member (tuffaceous conglomerates). We report stratigraphic subdivisions of the John Day Formation in the Clarno Unit area following both the A-through-I system of Peck (1964) and the identification of formal members of the eastern facies by Fisher and Rensberger (1972) as modified by Retallack and others (1996) and Bestland and others (1997).

Physiography

In the John Day River canyonlands of north-central Oregon, each of the three major geologic divisions has a distinctive geomorphic expression (Figure 4): (1) Resistant andesite and debris-flow units of the Clarno Formation form dissected hilly canyonlands that are largely covered by thin soils. (2) The much finer grained and less volcanically dominated John Day Formation forms broad benches that are commonly covered by coarse colluvium and landslide debris originating from resistant units upslope. (3) Capping many of the canyons and forming impressive cliffs are the resistant rocks of the Columbia River Basalt Group. Another prominent feature of this area is the thick and resistant welded tuff of member A of the basal John Day Formation, which forms a cuesta that can be traced throughout the area. The John Day Formation above this marker bed can be divided into a lower and upper part on the basis of geomorphic expression. The lower part consists of clayey and kaolinite-rich strata of the lower Big Basin Member, which weather to form a gently-sloping bench covered with

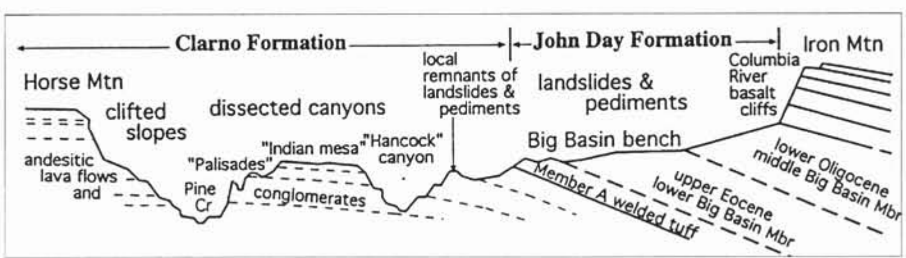


Figure 4. Sketch cross section of the Clarno area, illustrating the physiographic differences between the dissected canyons of the Clarno Formation, the broad, gently sloping benches of the lower John Day Formation, and the prominent cliffs of the Columbia River Basalt Group.

thick clayey soil. The Oligocene part of the John Day Formation contains tuffaceous strata rich in smectite clay that weather into steep badlands and sloping hills.

The erosional history of the area to its present-day topography began in the late Miocene after cessation of Columbia River Basalt Group volcanism and deposition of the mid-Miocene Mascall Formation. A major tectonic break occurred in north-central Oregon between the Mascall Formation, dominated by fine-grained alluvium, and the disconformably overlying late Miocene Rattlesnake Formation, dominated by fanglomerates of basaltic composition. Thus, faulting and uplift of central Oregon must have begun sometime in the late Miocene.

In the Clarno area, landslides consisting of large and seemingly coherent blocks of basalt from the John Day Formation and Columbia River Basalt Group have slid over clayey soils, confusing some of the distribution of basalt units (see map by Robinson, 1975). Pediment surfaces and colluvial soils dominated by basaltic fragments veneer much of the landscape. Small alluvial fans and dissected fanglomerate deposits of Quaternary age are common occurrences proximal to small canyons draining steep terrain of the Columbia River Basalt Group. Most of these Quaternary deposits overlie the John Day Formation. The fanglomerates contain caliche-cemented paleosol horizons.

Structure

Strata of the Clarno and John Day Formations and overlying flows of the Columbia River Basalt Group are gently to moderately folded, forming broad, open, generally northeast-plunging folds (Figure 3). This orientation is parallel to the elongation of the Blue Mountains in northeastern Oregon. Faults, on the other hand, strike west to northwest, generally in a direction normal to fold axes. They commonly show right-lateral strike-slip movement with displacements less than a few hundred meters. Deformation was caused by a northwestward-directed compressive (shear) stress which folded the strata and moved fault-bounded southern Clarno blocks westward, relative to the northern blocks. Because dips of the strata decrease upward stratigraphically, deformation was underway during deposition of Clarno Formation, between 55 and 45 Ma, and continued past the outpouring of Columbia River Basalt Group lava at 16–15 Ma.

CLARNO FORMATION LITHOSTRATIGRAPHIC UNITS (CLARNO AREA)

In the Clarno Unit area, the Clarno Formation contains laterally extensive and mappable lithostratigraphic units (Figures 2 and 3). These units are of three types: (1) andesitic debris-flow packages, (2) andesite lava flows, and (3) claystones. Smaller scale lithostratigraphic units, such as basalt flows or thin andesite flows, tuff beds, and minor red beds, were used to characterize and help identify larger stratigraphic packages. Of the three lithostratigraphic types, the debris- and andesite-flow units constitute the majority of the cliffs along the John Day River in the area south of Clarno bridge along the John Day River and along the western part of Pine Creek.

Lower Clarno Formation (unit Tcl)

Some older debris flows underlie the main Clarno Formation sequence in the Clarno Unit area (Figure 3). These debris flows consist of a sequence of boulder-sized, matrix-supported conglomerates that are exposed just to the west of Hancock Canyon and are referred to as lower Clarno conglomerate. These debris-flow deposits are of uncertain affinity and of local extent (Hanson, 1973, 1995) and are exposed in a structural dome or anticline west of Hancock Field Station (Figure 3). The anticline is a structural window into lower Clarno Formation strata that have been onlapped by later Clarno Formation deposits. The stratigraphic position and relationship of these older deposits with the dacite body are not clear.

Hancock dacite dome (unit Tcd)

A plagioclase-hornblende dacite porphyry is exposed in the hills and gullies to the northeast of Hancock Field Station (Figure 3, unit Tcd). The dome-shaped rock body is pervasively altered and in the northern part of its outcrop consists of compact breccia. Massive, nonbrecciated dacite is exposed in the bottom of gullies, from which a sample was dated at 53.6 ± 0.3 Ma (Table 1, sample no. 93602). Stratigraphic sections of strata directly overlying this igneous body do not show intrusive features such as baking, veining, hydrothermal alteration, and mineralization (Bestland and Retallack, 1994a). The overlying pebbly claystones contain boulders exclusively of weathered, altered hornblende dacite. The claystones are interpreted as well-developed paleosols of the Pswa pedotype (Bestland and Retallack, 1994a) that developed on an igneous body and incorporated colluvial debris (dacite clasts) from the underlying dacite. Thus, the dacite body was an erosional feature that was mantled by colluvium and soils.

Andesite of Pine Creek (unit Tcap)

The base of the stratigraphically coherent section in the Clarno Unit area is a thick andesite flow referred to as the andesite of Pine Creek (Figure 5a). The lava flows consist of dark-colored pyroxene-plagioclase andesite, and a sample from the west lobe was dated at 51.2 ± 0.5 Ma (Table 1, sample no. 93603). West of The Palisades a single flow (>50 m thick) occurs in two lobes, judging by their similar lithologies and chemical composition. These lobes terminate along the north side of Highway 218 and extend northward no more than 600 m into the Clarno Unit. The an-

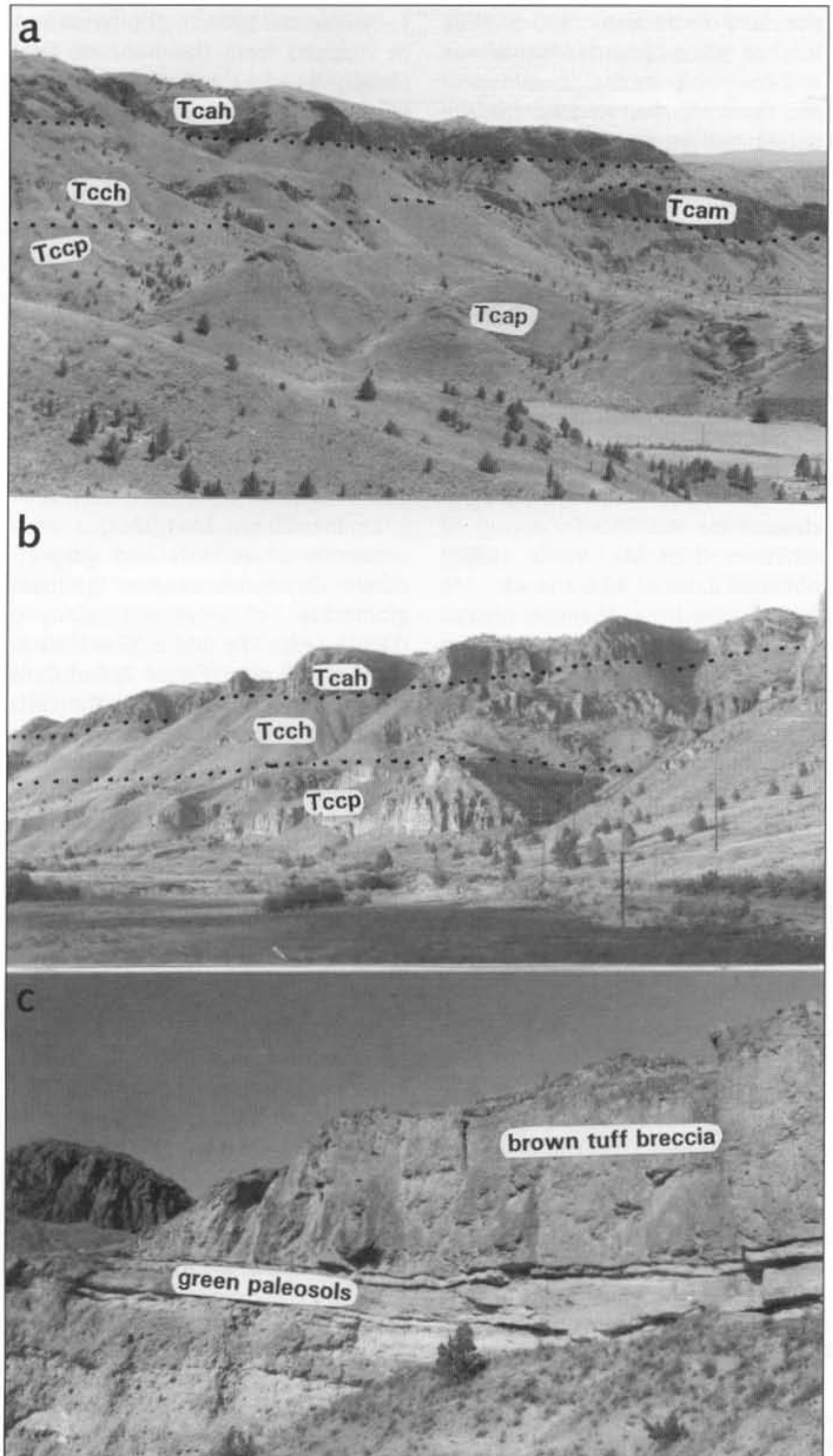


Figure 5. Photographs of West Face Cliffs: (a)—View to the south toward Horse Mountain, showing lithostratigraphic units in the Clarno Formation. (b)—View to the north at West Face Cliffs. (c)—Debris-flow deposits and paleosols in conglomerate of The Palisades in West Face Cliffs. Rock unit symbols as in map of Figure 3, but "T" added and Tcam=cawf.

desite flows have a very irregular upper surface that consists of breccia mantled by a weathered red saprolite.

Paleorelief of this unit is best exposed in cliffs along Pine Creek between The Palisades and the entrance to Hancock Field Station, where more than 40 m of paleotopography is onlapped by debris flows over a lateral distance of 200 m. Pockets of red and white claystones (paleosols) are preserved between the andesite and overlying debris flows and were mapped separately (Bestland and Retallack, 1994a).

Conglomerate of The Palisades (unit Tccp)

Onlapping the irregular surface of the andesite of Pine Creek is a thick (55 m) sequence of debris flows dominated by clasts of andesitic composition (Figures 5b,c). The conglomerate of The Palisades weathers to form the spectacular hoodoos along Pine Creek and in the lower part of the West Face Cliffs along the John Day River (Figures 5a-c). Most of the conglomerate is matrix-supported, moderately clast-rich, laterally continuous, and interpreted as floodplain debris flows (in the sense of Scott, 1988). The Palisade cliffs contain numerous clast-rich, channelized debris flows. Some are clast supported at their base. Hyperconcentrated flood flow deposits (in the sense of Nemec and Muszynski, 1982; and G.A. Smith, 1986) are common at the base of debris flows where they grade into debris-flow deposits. Well exposed at approximately the middle of this unit are several thin, green, clayey paleosols with wood fragments and leaf impressions (Figure 5c).

To the east of Cove Creek, conglomerate of The Palisades onlaps, thins, and pinches out against andesite of Pine Creek. Mantling the conglomerate of The Palisades is a saprolite horizon that is overlain by brown and red claystones (paleosols). These claystones erode to form a bench on the mesa between Hancock Canyon and Indian Canyon. This bench is also present on the north and west sides of Horse Mountain and along the canyon walls of Cove Creek.

Andesite of West Face Cliffs (unit Tcawf)

This thick andesite is locally present in the southern part of the project area south of Clarno along the John Day River (Figure 5a). Here, the unit is exposed in the lower half of the monolithic buttes on the west side of the river (Hills 2441 and 2373, sec. 9, T. 8 S., R. 19 E.) and consists of blocky, dark-colored, pyroxene-plagioclase andesite. At the base of Hill 2441 along the John Day River, the unit fills a paleovalley cut into the conglomerates of The Palisades. In the West Face Cliffs, the unit is clearly onlapped by conglomerate of Hancock Canyon.

Conglomerate of Hancock Canyon (unit Tcch)

Overlying both the red claystone beds at the top of the conglomerate of The Palisades and the andesite of West Face Cliffs is the conglomerate of Hancock Canyon (Figure 6). Like the conglomerate of The Palisades, clasts in this unit are principally of andesitic composition. This unit includes tuffaceous beds and a distinctive basalt flow but is dominated by matrix-supported boulder-debris flows. Deposits of this unit onlap the Hancock dacite dome. In the Clarno Unit area, the conglomerate of Hancock Canyon can be distinguished from the conglomerate of The Palisades by their more prominent bedding, less coarse-grained and massive texture, and common thin tuff interbeds.

The conglomerate of Hancock Canyon contains the Nut Beds fossil site, a 7-m-thick by 300-m-wide lens of silica-cemented sandstone and conglomerate that contains prolific floral remains. Radiometric age determinations on the Nut Beds and the Muddy Ranch tuff (also known as the "Rajneesh Tuff" and named in this paper the "tuff of Currant Creek," unit cct in Figure 3) are approximately 44 Ma; C.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 (oral communication, 1992), and Brent Turrin (for Manchester, 1990, 1994) used the same method on plagioclase of the Nut Beds for an age of 43.76 ± 0.29 Ma. Vance (1988) obtained dates of 43.6 and 43.7 Ma from fission track of zircon crystals in the Nut Beds and 44 Ma in the Muddy Ranch tuff near the Gable (Figure 3). The Muddy Ranch tuff is stratigraphically below the Nut Beds. Many large, well-preserved permineralized tree trunks and limbs of *Cercidiphyllum* (katsura) and *Macginitea* (sycamore) are in the conglomerates of Hancock Canyon.

Basalt of Hancock Canyon (unit Tchb)

A distinctive and widespread amygdaloidal basalt flow occurs stratigraphically in the upper half of the conglomerates of Hancock Canyon (Figure 6c). The basalt is holocrystalline, contains common plagioclase and pyroxene grains, displays pahoehoe flow structures and local columnar jointing, and has been dated at 43.8 ± 0.5 Ma (Table 1, sample no. 93613). The basalt can be mapped from the Hancock Field Station area to the Gable, is thickest (23 m) in the West Face Cliffs, but is not present east of Indian Canyon (Figure 3). This basalt flow can be traced along the cliffs of the John Day River south to Melendy Ridge, a distance of 14 km. The flow is very vesicular at its base, indicating that it flowed over moist terrain, where heat from the lava vaporized the moisture, and the steam penetrated upward into the still molten lava. Locally, these gas holes are filled with agate.

Claystone of Red Hill (unit Tcrh)

In the Clarno Unit area, a thick sequence of reddish and grayish-purple claystones overlies the conglomerate of Hancock Canyon (Figure 7a,b). The unit is 59 m thick in the Red Hill area (Figure 2) but thins dramatically to the east. In the cliffs on the west and north side of Horse Mountain; only a reddish saprolite with thin clay layer is present at this stratigraphic level. The unit at Red Hill contains a lower reddish paleosol sequence of very deeply weathered Ultisol-like paleosols (Lakayx pedotype) and an upper, less well developed Alfisol-like paleosol sequence (Luca pedotype, Retallack, 1981; G.S. Smith, 1988;). A stony tuff bed above the lowest Luca paleosol approximately divides the two paleosol sequences and has been dated at 42.7 ± 0.3 Ma (Table 1, sample no. 93653).

Conglomeratic beds are locally present in the claystones. At the southern tip of the Gable, a thick (18-m) coarse-grained conglomerate body (unit

Table 1. $^{40}Ar/^{39}Ar$ incremental heating ages for rocks from the Clarno Formation, eastern Oregon, by R.A. Duncan

Sample no.	Material	Total fusion Age (Ma)	Plateau Age[1] (Ma)	^{39}Ar % of total	Isochron age (Ma)	N[1]	$^{40}Ar/^{36}Ar$ intercept ± 1s	J[1]
93634	Andesite (plagioclase)	45.1	43.4 ± 0.4	70.3	44.1 ± 1.9	6	306.9 ± 14.6	0.001658
93653	Tuff (plagioclase)	43.0	42.7 ± 0.3	91.6	43.7 ± 0.6	5	289.8 ± 5.8	0.001403
91613	Basalt (plagioclase)	43.2	43.8 ± 0.5	74.3	45.2 ± 8.1	5	217.4 ± 264.9	0.001349
93603	Andesite (whole rock)	50.8	51.2 ± 0.5	62.4	48.3 ± 4.4	6	233.6 ± 339.2	0.001555
93602	Dacite (plagioclase)	57.2	53.6 ± 0.3	44.4	56.1 ± 0.6	5	289.8 ± 2.2	0.001680

[1] Plateau ages are the mean of concordant step ages (N = number of steps), weighted by the inverse of their variances.
J is the neutron fluence factor, determined from measured monitor $^{40}Ar/^{39}Ar$.

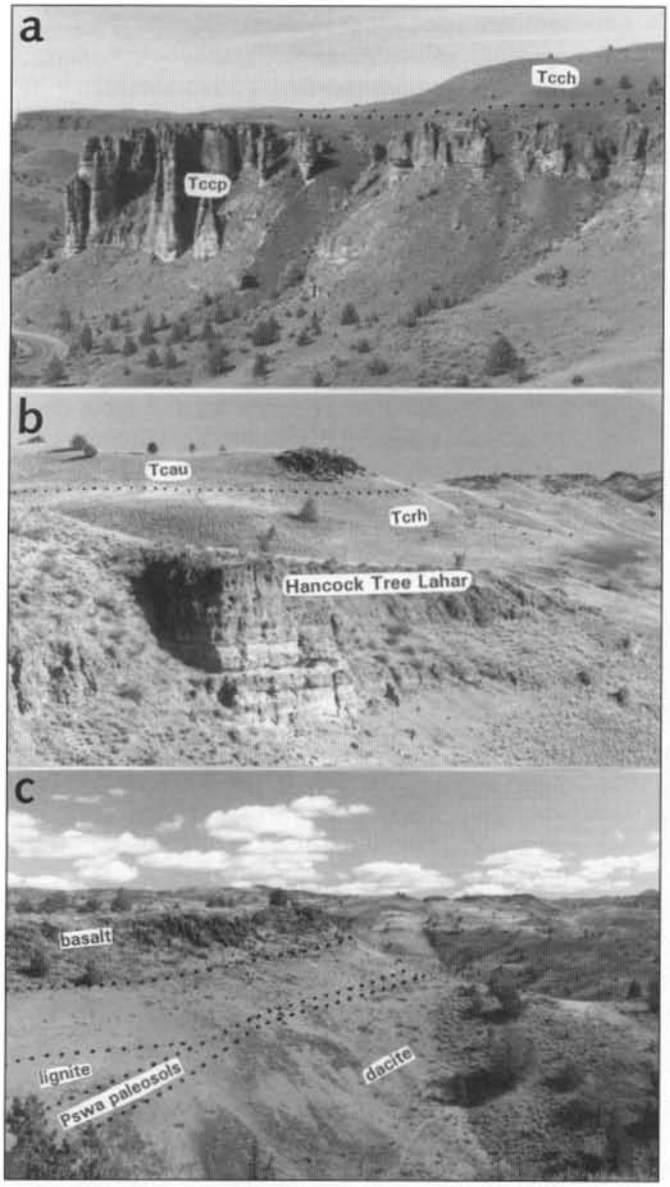


Figure 6. Photographs of The Palisades and Hancock Canyon. (a)—View to the west showing the conglomerates of The Palisades overlain by bench-forming claystone unit which in turn is overlain by conglomerates of Hancock Canyon. (b)—View to the east showing the conglomerate of Hancock Canyon overlain by claystone of Red Hill and the upper andesite unit. (c)—View to the east showing the margin of the dacite dome and onlapping strata. A series of trenches was dug down to bedrock at this location and documented the onlapping nature of a series of colluvial paleosols onto the dacite igneous body. Rock unit symbols as in map of Figure 3, but "T" added.

Tcrg) is interbedded with red claystones. The conglomerates are clast supported and contain rounded clasts of andesite and amygdaloidal basalt. They cut into red claystones and underlying units of the conglomerate of Hancock Canyon.

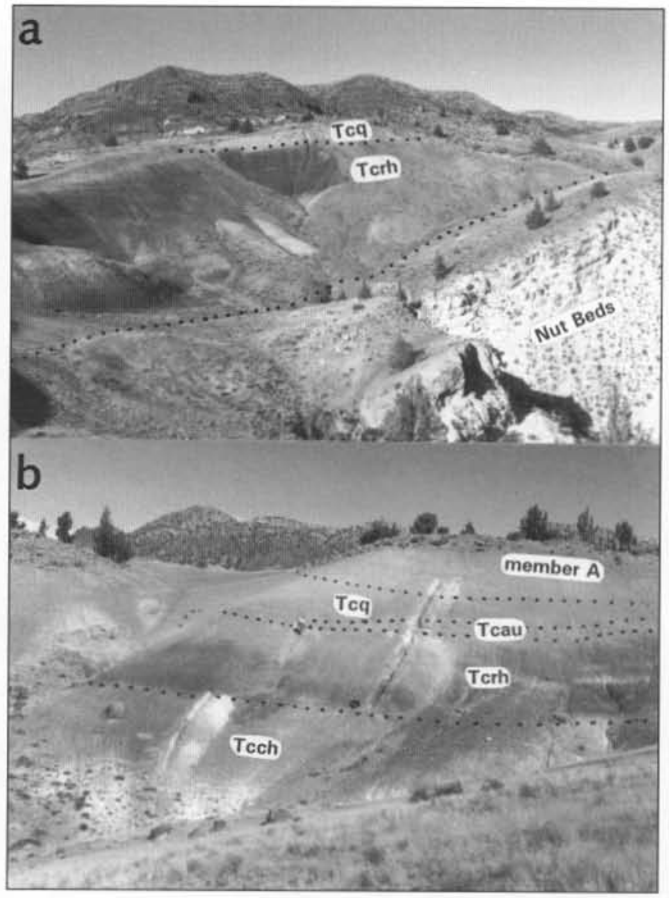


Figure 7. Photographs of upper Clarno Formation units. (a)—View to the north showing Red Hill and lithostratigraphic units in upper Clarno Formation (Nutbeds are in the upper part of the conglomerate of Hancock Canyon. (b)—View to the north showing Red Hill East and lithostratigraphic units exposed in the badlands. Rock unit symbols as in map of Figure 3, but "T" added and Tcq=cmq.

The claystones of Red Hill are prone to landslides. Most landslides in the area occur where thick exposures of these claystones are overlain by the welded tuff of member A of the basal John Day Formation. Good examples of these landslides occur on the east side of Indian Canyon. The landslides do not appear deep seated; the coherent blocks of member A form shallow, rocky slides.

Andesite of Horse Mountain (unit Tcah)

This thick andesite unit is extensively exposed in the Clarno area where it caps much of Horse Mountain (Figure 5a,b) and has been dated at 43.4 ± 0.4 Ma (Table 1, sample no. 93634). The unit consists of platy to blocky andesite that varies from pyroxene-plagioclase andesite to very porphyritic plagioclase dacite with traces of hornblende. Along the west and north side of Horse Mountain, the unit overlies a 2-m-thick red saprolite developed on the amygdaloidal basalt flow (unit Tchb) in the conglomerate of Hancock Canyon. 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.

An upper andesite (unit Tcau) is recognized above the andesite of Horse Mountain, based on stratigraphic position and lithology. On the rolling top of the western part of Horse Mountain, a plagioclase phyric, basaltic andesite flow is exposed above a 1- to 3-m-thick red claystone unit (paleosols) and below member A of the basal John Day Formation. This andesite has been mapped and identified by bulk rock geochemistry (Bestland and Retallack, 1994a). Lithologically and geochemically similar andesite crops out in the upper part of Hancock Canyon, where it underlies the siltstone of Hancock Mammal Quarry. In badland exposures to the east of Red Hill, a saprolitized andesite breccia can be traced into coherent exposure of this upper andesite unit.

Siltstone of Hancock Mammal Quarry (unit Tcmq)

The tan, clayey siltstones and cobble conglomerates of the Hancock Mammal Quarry beds are only locally present in the Red Hill-Indian Canyon area (Figure 8a). A diverse and important vertebrate fauna has been excavated from the Hancock Mammal Quarry, located stratigraphically in the uppermost Clarno Formation and below member A of the John Day Formation (Hanson, 1973, 1989, 1995). Pratt (1988) described Inceptisol-like paleosols from the Hancock Mammal Quarry. By her interpretation, the fossil remains accumulated as carcasses and were disarticulated in a fluvial point bar.

JOHN DAY FORMATION LITHOSTRATIGRAPHIC UNITS (CLARNO AREA)

In the Clarno Unit area, the John Day Formation has been mapped and stratigraphically subdivided by Robinson (1975) following Peck's (1961, 1964) informal subdivision of the John Day Formation on the basis of distinctive pyroclastic and lava flow units. In this paper, these pyroclastic and lava flow units are recognized and given the names defined by Peck (1964) and mapped by Robinson (1975); however, only distinct lithologic units were mapped in the Clarno Unit area. These volcanic units, along with the interbedded claystones, lacustrine shales, and tuffs, are here assigned to eastern facies members of the John Day Formation (Fisher and Rensberger, 1972).

Lower Big Basin Member (unit Tjlb)

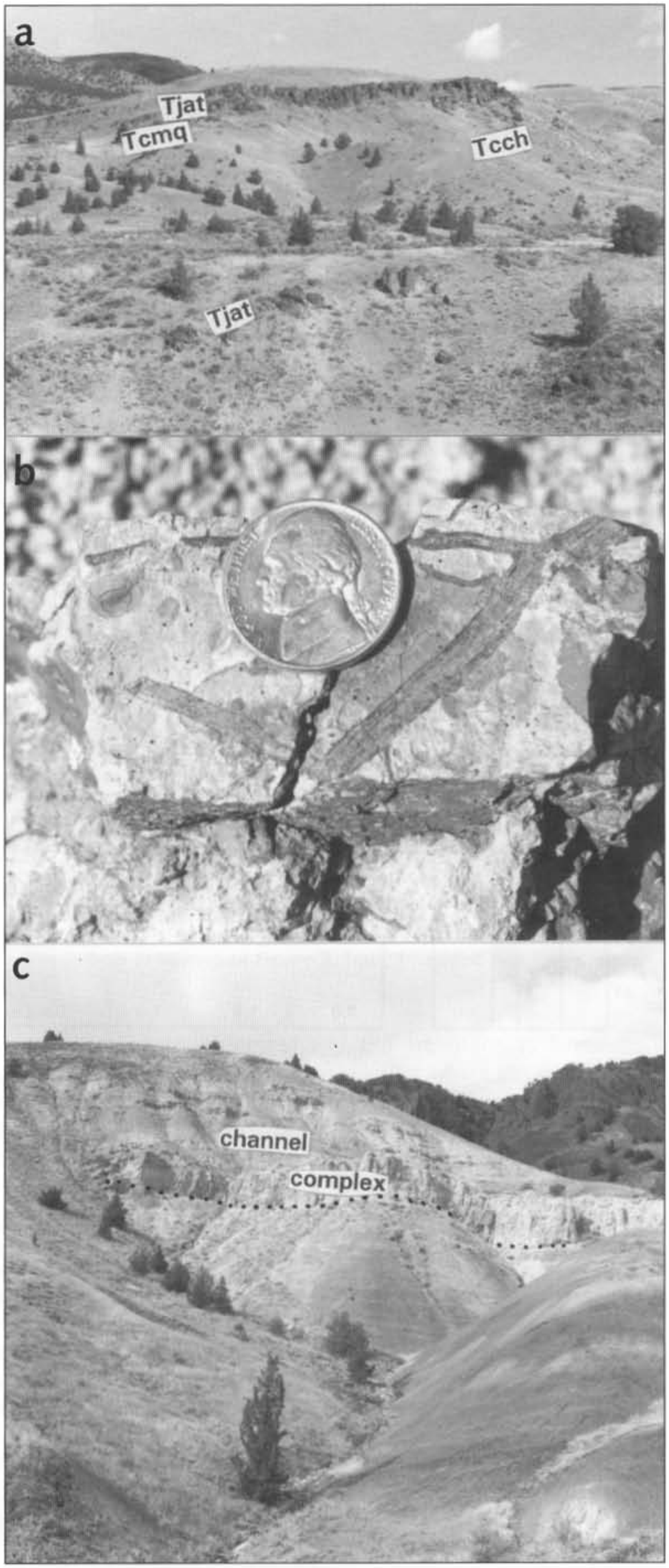
The lower Big Basin member in the Clarno Unit area includes all lithostratigraphic units from and including the welded tuff of member A of the basal John Day Formation up to a truncation surface marked in places by conglomerates and sandstones of probable Oligocene age (Figure 2). These sandstones and conglomerates are exposed in gullies to the west of the Slanting Leaf Beds which they stratigraphically underlie.

Welded tuff of member A (unit Tjat)—Rhyolitic pyroclastic volcanism of the John Day Formation is first recorded in north-central Oregon by an ash-flow tuff now redated in the Clarno area at 39.2 Ma and by a 39.7 Ma date from this tuff in the Painted Hills area (Bestland and others, 1997). This basal ash-flow tuff sheet is extensively exposed in the western facies (Peck, 1964; Robinson, 1975) where it is useful for delineating the Clarno surface at the onset of John Day volcanism (Figure 8a).

A lower, densely welded tuff forms prominent outcrops in the Clarno Unit area and is approximately 30 m thick. A perlitic vitrophyre occurs locally at the base and is best exposed in roadcuts at the Gable. At the very base of the ash-flow tuff are unwelded tuff deposits, some containing accretionary lapilli and plant remains (Figure 8b). Lithic fragments are common in the lower tuff as are bi-pyramidal (beta) quartz crystals. An upper, weakly welded to unwelded part of the ash-flow tuff, approximately 25 m thick, crops out extensively in the Clarno Unit area, where it commonly forms the dip slope on the member A cuesta. This unit also contains abundant bi-pyramidal quartz crystals but less lithic fragments than the lower densely welded part.

Member B basaltic andesite (unit Tjba)—In the Clarno Unit area, distinctive aphanitic basaltic andesite flows overlie member A. Red claystones are locally present between the two units. The flows consist of aphanitic to sub-glassy basaltic andesite that weathers into cobble-sized blocks. These basalts correlate with the member B trachyandesites of Peck (1964) and (Swanson, 1969) and have also been mapped in the Clarno Unit area (Robinson, 1975). Peck (1964) identified 460 m of very dark gray aphanitic flows of trachyandesite in the Ashwood area. In the Clarno Unit area, a 21-m-thick columnar-jointed basaltic andesite lava flow crops out at the head of Indian Canyon and is the thickest occurrence of member B in the area. Other small exposures are scattered throughout the area and are recognizable by their aphanitic texture and a weathering character that produces small, cobble-sized blocks—similar to Peck's (1964) description of member B. A set of basaltic andesite intrusions of this lithology forms a small hill between Hancock Canyon and Indian Canyon (NE¼ sec. 26, T. 7 S., R. 19 E.). The

Figure 8. Photographs of lower John Day Formation. (a)—View to the east showing the Hancock Mammal Quarry area and the welded member A tuff (unit Tjat) of the basal John Day Formation overlying the Hancock Mammal Quarry beds (unit Tcmq) and the conglomerate of Hancock Canyon (unit Tcch). (b)—Carbonized plant debris and accretionary lapilli from the unwelded base of the member A tuff. (c)—Tuffaceous claystone of the lower Big Basin member overlain by siltstone channel deposits.



rock contains pebble-sized cognate xenoliths of gabbro. Geochemically, lava flows and dikes are very similar in composition (Bestland and Retallack, 1994a).

White tuff of member F (unit Tjft)—A massive, white vitric tuff approximately 1–3 m thick is widespread but poorly exposed in the lower John Day Formation in the Clarno Unit area. This tuff is interbedded with clayey red beds of the lower Big Basin Member and has been referred to previously as the member F tuff. This vitric tuff was dated at the Whitecap Knoll (=White Knoll on map in figure 3) locality at 38.2 Ma (Bestland and others, 1997). Getahun and Retallack (1991) identified an Alfisol-like paleosol (Luca pedotype) directly below this tuff at Whitecap Knoll. Robinson and Brem (1981) identified a massive, white, vitric tuff located in a road cut just west of the Clarno Grange Hall on Highway 218 as the base of member F in this area. However, recent $^{40}Ar/^{39}Ar$ age determinations on the member F tuff in its type area in the western facies indicate an early Oligocene age (G.A. Smith, oral communication, 1996; Smith and others, 1996). And, according to Peck (1964), the weakly welded ash-flow tuff that defines the base of member F is not a widespread unit. Thus, the correlation of this tuff in the Clarno area with the western facies type area is not tenable with these recent dates.

Lower Big Basin Member claystones (unit Tjlb)—Widespread, thick, clayey, red beds in the lower part of the John Day Formation in the Clarno Unit are mapped as lower Big Basin Member, based on lithologic and stratigraphic similarities with the type section of this member in the Big Basin area of Picture Gorge. Recently recognized subdivisions of this member in a reference section from the Painted Hills area (Bestland and others, 1996, 1997; Bestland and Retallack, 1994b) are also recognized in the Clarno Unit.

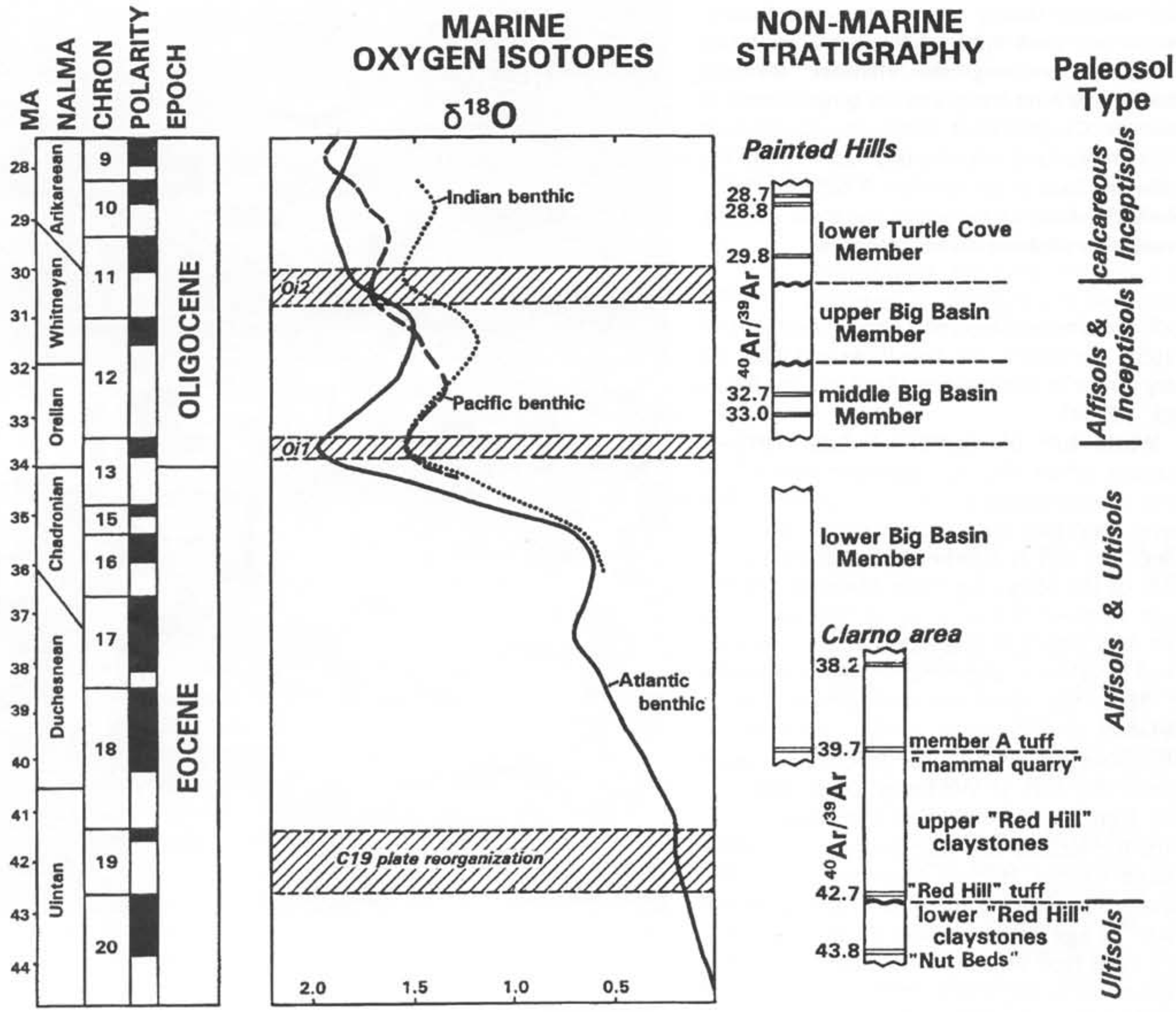


Figure 9. Correlation of nonmarine stratigraphy from central Oregon with marine oxygen isotopic record, using the geomagnetic time scale of Cande and Kent (1992, 1995) as modified by Berggren and others (1992, 1995) and $^{40}Ar/^{39}Ar$ radioisotopic age determinations from tuffs interbedded with paleosols. From Bestland and others, 1997.

The Eocene-Oligocene boundary is placed at 34 Ma (Swisher and Prothero 1990; Berggren and others, 1995). Marine isotopic data are from benthic foraminifera and are smoothed by linear interpolation (Miller and others, 1987). Oi1 and Oi2 are oceanic oxygen isotope cooling events (Miller and others, 1991).

The first major change in paleosol type occurs between the lower and upper red claystones of the Clarno Formation and corresponds with the chron 19 plate-tectonic reorganization (McGowran 1989). The dramatic change in paleosol type and the large truncation surface between the lower and middle Big Basin Members support the placement of the Eocene-Oligocene boundary at approximately 34 Ma according to $^{40}Ar/^{39}Ar$ age determinations from the central Oregon section. An early Oligocene climatic recovery is indicated by the presence of well-developed, clayey paleosols at the top of the middle Big Basin Member approximately dated at 32.0 to 32.7 Ma. A third major change in paleosol type between the upper Big Basin Member and lower Turtle Cove Member, at approximately 30 Ma, is synchronous with the Oi2 oceanic oxygen isotope cooling event.

Middle and upper Big Basin Members (unit Tjmb)

The middle and upper Big Basin Members were not delineated in the Clarno area as they have been in the Painted Hills area (Bestland and Retallack, 1994b). In the Clarno area, red-brown silty claystones, tuffs, and lacustrine shales with leaf impressions, similar to the middle Big Basin member in the Painted Hills, occur above clayey red beds (lower Big Basin Member) and below green tuffaceous strata with sanidine tuff. A sanidine tuff occurs in the lower part of the Turtle Cove Member in the Painted Hills (see Figure 9), where it was dated at 29.8 Ma. Additionally, the 33.6 Ma age determinations from the Slanting Leaf Beds and the well-documented Bridge Creek flora (Manchester and Meyer, 1987; Meyer and Manchester, 1997) from these strata allow correlation of this package with the middle Big Basin Member. In the Painted Hills area, age determinations of 33.0 Ma and 32.7 Ma on tuff beds (Bestland and others, 1997) are associated with the type locality of the Bridge Creek flora (Chaney 1924, 1948) and are contained within the middle Big Basin Member. Red, silty claystones stratigraphically above the Slanting Leaf Beds and below a cliff-forming channel complex (Figure 8c) are similar to Ticam and Skwiskwi pedotypes identified in the middle and upper Big Basin Members from the Painted Hills (see Bestland and others, 1997, for pedotypes).

At the base of the middle Big Basin Member and locally present in the Clarno area, are conglomerates containing weathered clasts of tuff and igneous flow rocks (Figure 2). In gullies to the west of the Slanting Leaf Beds, brown, calcareous paleosols overlie these conglomerates and underlie the lacustrine and carbonaceous shales of the Slanting Leaf Beds. These conglomerates fill an incised surface cut into underlying claystones of the lower Big Basin Member and represent a major truncation surface, similar to a truncation surface identified in the Painted Hills area (Bestland and Retallack, 1994b). This truncation surface approximates the Eocene-Oligocene boundary.

Member F basalts (unit Tjfb)—Alkaline olivine basalts of member F of the John Day Formation (Robinson, 1969) occur extensively in the Clarno area. Below Iron Mountain, John Day Formation basalts of member F are in contact with Columbia River Basalt Group. Lava flows of this unit are also interbedded with tuffaceous deposits and paleosols of the middle and upper Big Basin Members. The stratigraphically lowest alkaline basalt is less than 10 m above the Slanting Leaf Beds.

Turtle Cove Member

Tuffs and tuffaceous siltstones and claystones of the Turtle Cove Member are recognized in the Clarno Unit on the basis of correlation of tuffs in the western facies with this member in the eastern facies (Woodburne and Robinson, 1977). The Turtle Cove Member as well as the ash-flow tuffs of members G, H, and I are exposed in The Cove, on the west side of Iron Mountain above the John Day River, and have been mapped previously by Robinson (1975) and by Bestland, Blackwell, and Kays (unpublished mapping 1986 and 1988). These tuff units are significant in the context of correlating the Turtle Cove Member of the John Day Formation with the western facies of the John Day Formation.

Member G ash-flow tuff and related units are extensively exposed in the western facies (Robinson, 1975) and in the Clarno area along the Iron Mountain escarpment. This sanidine-rich tuff has been correlated with a sanidine tuff in the Painted Hills area (Hay, 1963; Woodburne and Robinson, 1977) which has been recently dated at 29.8 ± 0.02 Ma (Bestland and others, 1997).

The ash-flow tuff sheet of member H is also widespread in the western facies (Peck, 1964; Robinson, 1975) as well as in the eastern facies (Fisher, 1966), where it is referred to as the "Picture Gorge ignimbrite." Member H has been correlated with the Picture Gorge ignimbrite on the basis of lithology and stratigraphic position (Robinson and others, 1990). Two recent age determinations of this unit in the Painted Hills are both 28.7 ± 0.07 Ma (Bestland and others, 1997). This tuff is crystal poor and contains variable amounts of lithic fragments of rhyolite and tuff. In the Clarno area, two cooling units are present in the tuff, as has been recognized in the eastern facies by Fisher (1966). To the west of Clarno, closer to the source, only one cooling unit is recognized (Robinson and others, 1990).

Member I tuff in the Clarno area consists of a distinctive coarse-grained ash-flow sheet that occurs in scattered exposures high on the slopes of Iron Mountain. The tuff is up to 15 to 20 m thick and contains coarse pumice fragments, coarse vitric shards, and obsidian fragments.

SEDIMENTATION, VOLCANISM, AND PAST CLIMATE CHANGE

Clarno Formation depositional setting

The Clarno Formation sedimentary units in this area can be broadly grouped into coarse-grained debris-flow-dominated deposits and fine-grained, alluvial paleosol or overbank deposits. White and Robinson (1992) interpret the coarse-grained Clarno Formation deposits as proximal, nonmarine lahar aprons and reworked fluvial deposits that flanked stratovolcanoes, possibly in fault-bounded minibasins in a tensional arc setting—similar to the Quaternary High Cascade graben of the central Oregon Cascades (Smith and others, 1987; Taylor, 1990). Fine-grained overbank deposits and paleosols are common in the formation, however due to the poor exposure of these claystone units, their distribution and sedimentology has been largely ignored (Robinson, 1975; Swanson, 1969) except in a few places such as Red Hill (Retallack, 1981; 1991a) and in the Cherry Creek area where White and Robinson (1992) briefly describe a thick section of clayey red beds.

Depositional setting of fossil sites in conglomerate of Hancock Canyon—Conglomerates of Hancock Canyon have a mix of debris-flow deposits, fluvial conglomerates, and tuff beds. Compared to the conglomerate of the Palisades, the conglomerate of Hancock Canyon, with its abundance of flood-surge or hyperconcentrated deposits and fluvial reworked beds, indicates a lower gradient or more distal depositional setting.

Within the Clarno area are numerous fossil plant localities (including several new sites, see Bestland and Retallack, 1994a) that indicate apparently dissimilar climates. The classic Nut Beds site yields plant fossils strongly indicative of a tropical to paratropical climate (Manchester, 1981, 1994). In contrast, at the same stratigraphic level and in a similar debris-flow depositional environment, some fossil plants found in Hancock Canyon suggest temperate conditions. It is likely that the Nut Beds flora represents a lowland, floodplain rain forest, like the selva of tropical Mexico, whereas the Hancock Tree flora represents an early successional forest located on an unstable braid plain. The flora has similarities to higher altitude forest with affinities to cooler climate, like the Liquidambar oak forests of Mexico (Gómez-Pompa, 1973).

Paleosols and overbank deposits—An overbank to piedmont alluvial setting is interpreted for the Red Hill claystones, based on laterally continuous paleosol horizons present in Red Hill and channel conglomerates interbedded with the claystones. The upper Red Hill section contains a thick stack of red Luca paleosols with few gleyed intervals. A large channel-fill conglomerate is interbedded with the claystones of Red Hill at The Gable (Bestland and Retallack, 1994a), which indicates that large channels did exist on the alluvial plain.

Thick accumulations of alluvial paleosols occur in scattered pockets elsewhere in the Clarno Formation. Their distribution is not widespread, probably due to rapid aggradation of coarse-grained units followed by incision during volcanic quiescence. Only occasionally did alluvial plains exist for a sufficient length of time for the accumulation of finer grained alluvium. Red Hill sits stratigraphically near the top of the Clarno Formation and probably marks the end of explosive andesitic volcanism in this part of the Clarno arc.

John Day Formation depositional setting

The John Day Formation represents a nonmarine back-arc basin that received mostly pyroclastic detritus from Cascade sources to the west. The formation becomes finer grained from west to east, following the dispersal pattern of pyroclastic material (Fisher, 1966; Robinson and others, 1984). The ash-flow tuffs of the John Day Formation contain sanidine and quartz and are rhyolitic (Robinson and others, 1990). Additionally, geochemical analyses of tuff beds (Hay, 1962, 1963; Fisher, 1966) and C horizons of paleosols (Fisher, 1966; Getahun and Retallack, 1991; Bestland and Retallack, 1994a,b) indicate a rhyolitic to rhyodacitic composition for the tuffs and tuffaceous alluvial deposits. The western facies ash-flow tuff sheets thicken toward the Warm Springs and Mutton Mountain areas. Taken together, these facts support an interpretation of a rhyolitic source for the John Day Formation that was separate from the Western Cascades.

Alluvial paleosols—The thick, colorful claystone and tuff sequences so well known from the John Day and Clarno Formations are now thought to be dominated by paleosol horizons (Retallack, 1981, 1991a,b; Bestland and others, 1994, 1996, 1997; Bestland, 1997). Furthermore, most of the paleosols and their associated, although pedogenically modified, substrates are interpreted as alluvial, and in a few cases colluvial, deposits. Most of the paleosols in the John Day and Clarno Formations are interpreted as floodplain paleosols, based on the following general considerations: They are relatively laterally continuous and show evidence of both well- and poorly drained conditions. They lack coarse-grained channel bodies, which indicates the predominance of vertical floodplain accretion. Many different paleosol horizons have been identified and interpreted, and these paleosols can be broadly grouped into floodplain setting (alluvial) and hillslope setting (colluvial) soil-forming environments. Landscape aggradation in the form of floods, pyroclastic air fall, wind-blown dust and ash, and colluvial movement from upslope locations caused vertical accretion of soil horizons. Larger scale additions of alluvium and colluvium periodically buried the landscape and caused new soils to form on these deposits. Aggradational periods were interspersed with episodes of downcutting, during which the alluvial and colluvial basin fill would be partially removed (Bestland and others, 1997).

Eocene-Oligocene transition

The long stratigraphic sequence of paleosols in the upper Clarno and lower John Day Formations record a dramatic paleoclimatic change. This is the transition from the Eocene to the Oligocene, when the Earth's climate and biota changed from the warm, mostly subtropical world of the Mesozoic and early Cenozoic to the glaciated world of today, or from the "hot house" to the "cold house" (Prothero, 1994). These climatic and biotic changes are centered around the Eocene-Oligocene boundary, with the changes appearing to be stepwise over several million years on either side of this boundary (Wolfe, 1978; Miller and others, 1987, 1991; Retallack, 1992; Bestland and others, 1997).

Recent work on the timing and global correlation of the Eocene-Oligocene boundary (Swisher and Prothero, 1990; Prothero and Swisher, 1992; Cande and Kent, 1992) allows for a comparison of the stratigraphy and age determinations from the central Oregon stratigraphy with the global data base of climate change (Bestland, 1997; Bestland and others, 1997). Many of the existing global climate change data come from deep-sea sediments and their oxygen and carbon isotopic record (Figure 9). In the John Day Formation, climatic steps centered around the Eocene-Oligocene boundary correspond with member boundaries (Figure 9). Most notable is the abruptness of the Eocene-Oligocene climatic transition. The short time span of this change is not apparent from paleontological evidence of vertebrates and plant fossils in the Pacific Northwest because of the incompleteness of the fossil record. The paleoclimatic record from paleosols in the Clarno and John Day Formations, in contrast, is much more complete.

Paleoclimate and depositional summary

A dramatic change in depositional setting from an active volcaniclastic apron of the conglomerates of Hancock Canyon to the quiet floodplain represented by the claystones of Red Hill records the the cessation of proximal volcanic activity in at least this part of the Clarno area. In the lower part of Red Hill, strongly developed, Ultisol-like paleosols dominate the strata and represent long periods of soil formation in a humid subtropical climate. These paleosols are the most weathered paleosols in the upper Clarno and lower John Day Formations. In the upper part of Red Hill, strongly developed Alfisol-like paleosols dominate the section and represent shorter periods of soil formation in a similar but probably drier humid subtropical climate (Bestland and others, 1997). The change from Ultisol- to Alfisol-like Luca paleosols is interpreted to be the result of climatic cooling and drying during the late Eocene (Figure 9). Changing paterns of oceanic circulation and volcanism are hypothesized to have caused a late Eocene climate change at about 42 Ma (McGowran, 1989). The hiatus in volcanism recorded in the Red Hill section from 44 Ma to about 40 Ma, when John Day or Cascade volcanism began, was a period of sporadic volcanism transitional from the Clarno to the Cascade arc. Following this volcanic hiatus of approximately 2–4 million years, renewed volcanism, represented by the andesite of Horse Mountain (unit Tcau), rejuvenated the alluvial system with fresh andesitic material and caused the deposition of the Hancock Mammal Quarry beds. These paleosols are too weakly developed to interpret much in the way of paleoclimate, except that it was relatively humid.

With the onset of John Day volcanism, the alluvial material changed from andesitic detritus to fine-grained rhyodacitic ash. In the lower Big Basin Member of the Clarno Unit area, strata contain strongly developed Alfisol- and Ultisol-like paleosols. The geochemical composition of these lower John Day paleosols is much the same as that of upper Clarno paleosols and indicates little, if any, climatic change from late Clarno time to early John Day time. Not until approximately 34 Ma, at the Eocene-Oligocene boundary, did the climate change dramatically (Figure 9). In the Clarno area, this boundary is marked by the contact between the lower and middle Big Basin Member to the middle Big Basin Members. Paleosols formed after this transition are higher in base cations and lower in Fe and Ti than late Eocene paleosols. The climate change from subtropical to temperate conditions across this boundary is contrasted dramatically by a comparison of the Eocene Nut Beds flora (tropical to subtropical forest) and Red Hill clayey, Ultisol-like paleosols with the Oligocene Bridge Creek flora of the Slanting Leaf Beds (temperate forest) and middle Big Basin Member tuffaceous, Inceptisol-like paleosols.

ACKNOWLEDGMENTS

This report represents the combined efforts of E.A. Bestland and G.J. Retallack under contract with the National Park Service (Bestland and Retallack, 1994a,b), the University of Oregon Geology Field Camp and its director, M. Allan Kays, and Portland State University Geologic Field Methods directed by P.E. Hammond. Discussion with T. Fremd, J. Jones, E. Taylor, R. Goodfellow, and A. Mindzenty have added to our understanding of the geology and paleontology of this area. R.A. Duncan of the College of Oceanic and Atmospheric Sciences, Oregon State University, kindly supplied age determinations for a number of samples.

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DOGAMI PUBLICATIONS

Released July 22, 1998

Tsunami hazard map of the Seaside-Gearhart area, Clatsop County, Oregon, by George R. Priest, Edward Myers, Antonio Baptista, Robert Kamphaus, Brooke Fiedorowicz, Curt D. Peterson, and Thomas S. Horning. Interpretive Map Series IMS–3, scale 1:12,000, $6.

This map shows how three different tsunamis might affect the area. Computers were used to simulate three different local earthquakes and the tsunamis they might cause. These simulations were used in conjunction with field–based mapping and analyses of core samples to produce the map.

The map has an aerial photo as its base, so that streets and buildings can be identified and their danger from flooding or their use as potential evacuation routes assessed. Each potential tsunami flooding area is outlined, as is the actual flooding level of the 1964 tsunami that was triggered by a great earthquake in Alaska and killed people as far away as Crescent City, California.

Because of the potential loss of life and property from these events, many government agencies have contributed to this map and will continue to work with the communities. The Oregon Graduate Institute of Science and Technology, Portland State University, and the National Oceanic and Atmospheric Administration provided scientific research to produce the map. The State of Oregon and the City of Seaside helped fund the project.

Released December 11, 1998

Geology of the Henkle Butte quadrangle, Deschutes County, Oregon, by E.M. Taylor. Geological Map Series GMS–95, scale 1:24,000, 5 p. text, $10.

A new geologic map of the Henkle Butte quadrangle helps explain the geology of the eastern side of the Cascade Range. The map includes part of the Deschutes National Forest.

A diverse mix of volcanic and sedimentary rock covers the area. Construction aggregrate has been mined from the local cinder cones and gravels. Until about 1.6 million years ago, the landscape was mostly rim-rock lava and a few river deposits. Since then, the area has been eroded by streams that carved the Fremont, McKenzie, and Deep Canyons (now

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BOOK REVIEWS

Living with Earthquakes in the Pacific Northwest, by Robert S. Yeats. Oregon State University Press, 101 Waldo Hall, Corvallis, Oregon 97331-6407, osu.orst.edu/dept/press, 1998. 309 p., ISBN 0-87071-437-6, soft cover, $21.95. [Available from DOGAMI: See last page of this issue.]

Accurately forecasting the next major earthquake in the Pacific Northwest is an impossible task. The notion that Mother Earth transmits reliable data for this kind of event isn't supportable by past measurable events. So what is the next best thing to do to prepare for the upcoming inevitable earthquake?

Answer: Read *Living With Earthquakes In The Pacific Northwest* by Dr. Robert S. Yeats!

Dr. Yeats' credentials are well established and revered through a quarter century of earthquake study and scientific analysis on inner earth rumblings around the world. He is a senior consultant for Earth Consultants International and a professor emeritus in the geosciences department at Oregon State University.

Unlike many other earth science authors, Yeats focused on a layman's interest in and background of scientific knowledge. Simply put, the book is an easy read and down to earth. Yeats' use of humor, graphs, and photographs makes this an informed and understandable writing.

What can you expect to learn? For one, inner-earth disturbances result from strained rock. A detailed explanation of this straining and its relation to tectonic movement brings the reader to an understanding of the what, where, and why of earthquakes. Also, shaky ground, landslides, and big sea waves are all possible results of inner-earth disturbances. Readers will recognize the locations of many recent earthquake events like Scotts Mills, Klamath Falls, Oregon's Capitol Building, and Mount St. Helens. For the lay reader, Yeats provides six pages of glossary entries to help bring understanding to geoscience words like asperity, Holocene, P wave, and shear wall. An extensive bibliography suggests additional reading for those interested.

It is true that we cannot prevent earthquakes, but it is also true that we can learn to live with them and to survive them. Are we ready for the next big one? Most experts say we are not, but Yeats' book details a number of measures one can put in place to counter a destructive event. Considerations for purchasing earthquake insurance, readying the home for shaking and shifting ground, and design implications for structures large and small are all clearly detailed. Also, there is a discussion of the role of state and local governments in dealing with earthquakes.

Dr. Yeats has succeeded in communicating vital information to his readers. The public's next step is to pick up a copy and to read it. With recent reports of swarms of small disturbances under Mount Hood and frequent articles about the Cascadia subduction zone, which lies a few miles off Oregon's coastline, it becomes increasingly important that the general public become informed. Reading this book is the right step in that direction.

—Don Christensen
DOGAMI Governing Board Member
Depoe Bay, Oregon

Islands and Rapids. A Geologic Story of Hells Canyon, by Tracy Vallier. Confluence Press, Lewiston, Idaho, 1998. 151 p., ISBN 1-881090-30-2, soft cover, $25. [Available from DOGAMI: See last page of this issue.]

Islands and Rapids is highly recommended reading for anyone planning a visit to the Hells Canyon country of eastern Oregon. Here at last is a comprehensive geologic guide to one of North America's scenic treasures, written by Dr. Tracy Vallier, the man who has spent the most time and effort to decipher the geologic mysteries of Hells Canyon.

Published by Confluence Press (Lewis-Clark State College), the 151-page volume is an entertaining and informative geologic expose, filled with pictures and maps and geologic descriptions. The author, Tracy Vallier, has taken the time to explain complex geologic terms. Dr. Vallier has also provided the reader an intimate look at his personal 30-year struggle in unravelling Hells Canyon's geologic history. I strongly recommend that anyone interested in the geologic story of Hells Canyon take a look at this book. It is an enjoyable read.

—Mark L. Ferns
Oregon Department of Geology and Mineral Industries, Baker City Office

Correction

Author Frank Hladkey has called to our attention that an error slipped into Table 1 of his recent article about Upper Table Rock and Lower Table Rock. In the July/August 1998 issue (v. 60, no. 4), on page 85, in the analyses for oxides, the numbers for Na_2O were reported incorrectly. The correct values are listed below along with the respective sample numbers:

Sample no.	Na_2O
BAG-614	4.51
BAG-615	4.52
BBG-202	4.59
BBG-203	4.18
BBG-207	3.98

We apologize to our readers for the oversight and are grateful to Frank for catching it. □

New fossil book at Nature of the Northwest

Oregon Fossils, by Elizabeth and William Orr. Kendall/Hunt Publishing Company, Dubuque, Iowa, 1999. 381 p., ISBN 0-7872-5454-1, soft cover, $40.95.

The book discusses Oregon's fossils in the context of their original environments and of the people who discovered and studied them. □

Report on Colombia earthquake damage to lifelines

by Yumei Wang, Oregon Department of Geology and Mineral Industries

On January 25, 1999, a magnitude 5.9 earthquake occurred near the city of Armenia, Colombia, and so far more than 400 aftershocks have been registered. Current reports include over 700 confirmed deaths, over 180,000 homeless, and numerous survivors needing food, medical aid, and clothing. Conditions are made worse by civil unrest, particularly in the two major cities of Armenia and Pereira, and by continuing rainfall that acts as an additional cause for more landslides that have already affected most of the mountain roads.

Structures and lifelines were considerably damaged. Quantification of the damage and losses is practically impossible, because among the local authorities there is no uniform terminology and system of distinguishing types of damage and loss.

A preliminary lifeline damage summary was compiled by Curt Edwards, Chair of the Earthquake Investigation Committee of the American Society of Civil Engineers Technical Council on Lifelines Earthquake Engineering (ASCE-TCLEE). Edwards is currently assessing the need and feasibility to dispatch a TCLEE investigation team to report on the lifeline damage. [Yumei Wang from DOGAMI is one of the possible team members.–*ed.*] However, Edwards warns that Colombia is "considered one of the most dangerous countries in the world for travel, even without the effects of an earthquake," and such a team would put an additional burden on local authorities who are already stretched to the limits of their capabilities in the face of the current situation of food shortages, looting and protesters, limited trash collection, and spreading diseases.

Edwards provided the following list of selected lifeline damage to towns shown on the map below:

Armenia (223,000 inhabitants, more than 500 fatalities, more than 57 percent of homes affected): Civil unrest; no trash service; health problems evident, and vaccinations underway; no water, no electricity, aqueduct out, airport control tower out of service.

Pereira: Civil unrest, landslide threat to sever-water aqueduct, airport available only to relief efforts, electricity interrupted.

Cajamarca: Landslides blocking roads; other transportation problems.

Alcalá: Only partial telephone service, landslides, road blockages, and other transportation problems.

Ulloa: No communications.

Caicedonia: Very difficult telephone communications, hospital damaged.

Obando: Health center damaged.

Calarcá: Hospital damaged, only extreme emergencies treated, aqueduct inlet destroyed, roads blocked.

Montenegro: No electricity, landslides.

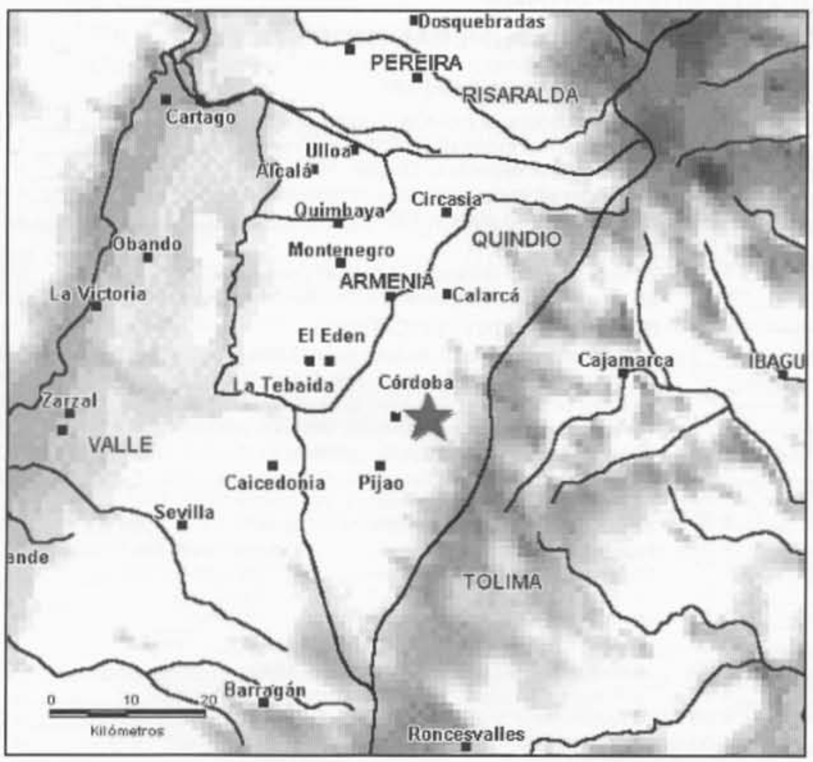
Córdoba: Hospital collapsed.

La Tebaida: Water and electricity services interrupted.

Pijao: Electrical service out.

Quimbaya: Electrical service out.

More information can be obtained (in Spanish only) from the website pages of the Observatorio Sismológico del SurOccidente (O.S.S.O.) at the following address: http://osso.colombianet.net □



Above and left: Location maps of western portion of Colombia. Rectangle indicates approximate outline of detail map on left. Star indicates earthquake epicenter. Sources: Observatorio Sismológico del SurOccidente and Lexikografisches Institut, München.

(Continued from page 19)
dry) and by Squaw Creek. The broad, level plains now support residential and agricultural development.

Released December 16, 1998

Using earthquake hazard maps. A guide for local governments in the Portland metropolitan region, by Spangle Associates, Urban Planning and Research, Portola, California. Open-File Report O–98–04, 45 p., $10.

The report was prepared for Metro, the regional government for the Portland metropolitan area, and originally published by Metro. The release by DOGAMI is intended to make the report available to a wider audience, because it applies in other densely populated regions as well..

The 45-page report discusses the state and regional context for the local use of earthquake hazard maps in zoning, subdivision, siting of public facilities, and seismic retrofitting. It focuses on local government actions but recognizes that all levels of government, businesses, community organizations, households, and individuals play roles in reducing a community's vulnerability to earthquakes.

Released January 4, 1999

Earthquake damage and loss estimate for Oregon, by Yumei Wang. Open-File Report O–98–03, 208 p., $40.

Earthquake damage in Oregon: Preliminary estimates of future earthquake losses, by Yumei Wang and J.L. Clark. Special Paper 29, 61 p., $10.

Statewide, county-by-county earthquake damage estimates are presented in the two reports, in full detail (Open-File Report) and in a less technical summary (Special Paper).

Wang's study analyzed the Cascadia subduction zone and all faults in the state that have a 10-percent chance of causing an earthquake in the next 50 years.

Released January 14, 1999

Water-induced landslide hazards, western portion of the Salem Hills, Marion County, Oregon, by A.F. Harvey and G.L. Peterson. 1998, Interpretive Map Series IMS–6, 1:24,000, $10.

This is a pilot project with participation by federal, state, and local governments. The Salem Hills are a landslide-prone area with intensive development in the southern part of the city. This area is important because the sliding is regional and cannot be easily studied or controlled in tax-lot-sized parcels.

The map outlines six levels of risk. The consulting firm Squier Associates mapped the area.

Geology of the Fly Valley quadrangle, Union County, Oregon, by M.L. Ferns. 1998, Geological Map Series GMS–113, 1:24,000, $10.

The Fly Valley area covers about 55 mi^2 on the headwaters of the Grande Ronde River in the Wallowa Whitman National Forest and marks the eastern flank of a large, newly recognized, 25-million-year-old volcanic center.

Major geologic resources found in the area include aggregate for road building, perlite, and decorative facing stone. Some of the hydrothermal alteration zones contain thundereggs and opal that may be of interest to mineral collectors and rockhounds.

Released February 1, 1999

Mist Gas Field map, 1999 edition. Open-file Report O–99–01, map scale 1:24,000, production statistics for 1993–1998, $8. □

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