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Deschutes Basin field trip guide

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The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 6th ed., 1978.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

Cover photo

Deschutes River Canyon near Steelhead Falls in Jefferson County. Late Miocene volcaniclastic sediments and ignimbrites of the Deschutes Formation form the cliffs on the right side of the river and in the background. Pleistocene intracanyon basalt flows form the prominent benches on the left side of the view and in the middle ground. Photo by Gary A. Smith. See related field trip guide by Smith beginning on next page.

OIL AND GAS NEWS

Mist Gas Field activity

Nahama and Weagant Energy Company began a multi-well drilling program at the Mist Gas Field, Columbia County, during October. The CER 11-16-64 well, located in sec. 16, T. 6 N., R. 4 W., was drilled to a total depth of 2,328 ft and was completed as a gas producer. The well is currently suspended, awaiting pipeline connection. The CER 41-21-64 well, located in sec. 21, T. 6 N., R 4 W., was drilled to a depth of 2,121 ft and is an indicated gas producer that is currently suspended waiting for production testing. The LF 13-35-65 well, located in sec. 35, T. 6 N., R. 5 W., was drilled to a total depth of 2,150 ft and was plugged and abandoned.

Northwest Natural Gas Company began drilling at the Mist Gas Field Natural Gas Storage Project during November. The well IW 33ac-3, located in sec. 3, T. 6 N., R. 5 W., will be an injection-withdrawal well in the Flora Pool.

ARCO Oil and Gas Company plugged a number of wells during October and November. These wells are depleted former producers and are no longer capable of gas production. The plugged wells are the CFI 12-1, LF 11-31-64, LF 23-36, LF 41-35, CC 11-34-65, CC 43-27, Busch 14-15, Foster 42-30-65, CC 4, CC 34-4-65, and LF 12-33.

Civil penalty legislation proposed

During the 1991 legislative session, the Oregon Department of Geology and Mineral Industries (DOGAMI) intends to present a bill that will provide civil penalty authority to the agency as part of its regulatory authority. The bill would authorize DOGAMI to impose civil penalties for violations of certain provisions of statutes relating to reclamation of surface lands and conservation of oil and gas and geothermal resources. For further information, contact Dennis Olmstead at DOGAMI's Portland office.

Recent permits

Permit no.	Operator, well API number	Location	Status, proposed total depth (ft)
451	Nahama and Weagant CER 14-16-64 36-009-00277	SW¼ sec. 16 T. 6 N., R. 4 W. Columbia County	Application; 2,500

□

DOGAMI 1991 open house announced

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces its second annual Open House and Information Exchange Session. The event will be held February 6, 1991, from 2 to 5 p.m. in downtown Portland at the Standard Plaza Building, 1100 SW 6th Avenue, in 3rd-floor meeting rooms A and B.

This is an opportunity to visit with the entire staff of the Department and learn firsthand about the agency's current activities. Displays will provide information on geologic mapping, earthquake hazard assessment, mineral resource studies including gold and industrial minerals, natural gas assessments, mined land reclamation, and regulation of drilling. The Department's laboratory, publication section, and sales office will also be featured.

The Department invites all those interested in its work to come and meet with the staff and share the refreshments that will be served. The Standard Plaza Building is two and one-half blocks north of the Portland State Office Building. □

A field guide to depositional processes and facies geometry of Neogene continental volcaniclastic rocks, Deschutes basin, central Oregon

by Gary A. Smith, Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131

INTRODUCTION

Sedimentary facies form a large part of the preserved stratigraphic record of most volcanic provinces. Study of volcaniclastic sequences adjacent to the Cascade Range has proven to be important for two reasons. First, in most parts of the Cascades, there is not a complete exposed record of Tertiary volcanism, and sedimentological and stratigraphic studies in adjacent sedimentary sections have contributed substantially to an understanding of the composition of extruded products, style of eruptive activity, and tectonic history of the arc (Smith and others, 1987; Smith and others, 1988). Secondly, pyroclastic volcanism generates large volumes of fragmental material over geologically instantaneous time intervals, resulting in highly episodic delivery of extraordinary sediment volumes to adjacent fluvial basins by a variety of transport and depositional processes involving a range of sediment concentrations and discharge characteristics. The types, distribution, and geometric relationships of the resulting lithofacies differ markedly from those illustrated by most alluvial sequences in nonvolcanic regions (Smith, 1987a,b, 1988, in press).

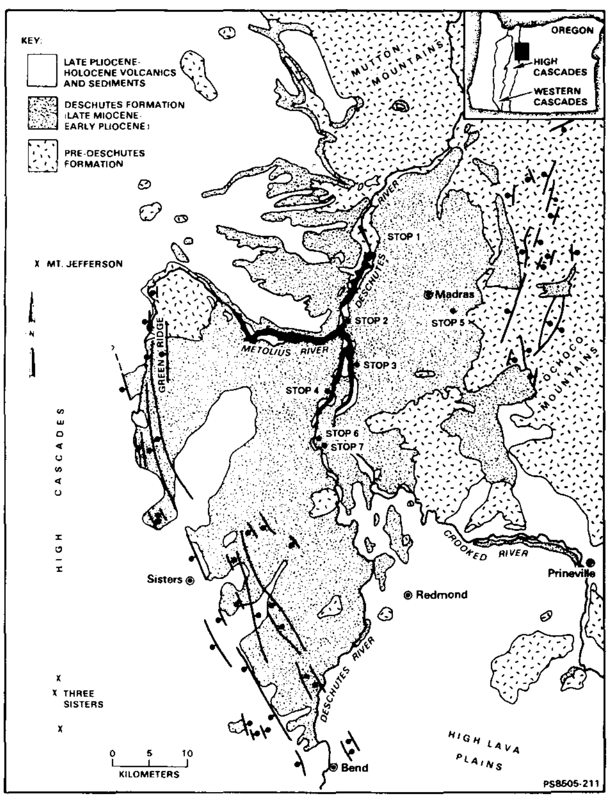


Figure 1. Generalized geologic map of the Deschutes basin and adjacent areas showing locations of field-trip stops. Structures along the western margin of the basin include the late Miocene-Pliocene Green Ridge fault zone, locally bounding the central Oregon High Cascade graben, and the Quaternary Tumalo fault zone between Sisters and Bend.

The purpose of this field trip is to illustrate the nature of synvolcanic sedimentation in a dissected Neogene fluvial basin. Emphasis is placed on (1) interpretation of depositional processes, distinguishing volcaniclastic materials emplaced by primary volcanic processes from those resulting from secondary sedimentary reworking, and (2) interpretation of volcanic and tectonic development of the central Oregon Cascade Range from examination of a primarily sedimentary record. The guide was prepared for an excursion to follow the 1991 Midyear Meeting of the SEPM, The Society for Sedimentary Geology, in Portland, Oregon. The reader is referred to Smith (1986b; 1987d; in press), and Smith and others (1987) for additional background information and to Robinson and Stensland (1979), Smith (1987a,b), Smith and Hayman (1987), and Sherrod and Smith (1989) for geological maps of areas included in this guide. Additional field guides describing this area include Smith and Priest (1983), Taylor and Smith (1987), and Bishop and Smith (1990).

GEOLOGIC SETTING

The Deschutes basin is a broad valley extending from the Ochoco Mountains on the east to the Cascade Range on the west, and from the Mutton Mountains on the north to the High Lava Plains on the south (Figures 1 and 2). No structural margins to the basin are clearly defined. Late Cenozoic aprons of volcanic and volcaniclastic material extended eastward from the Cascades and onlapped older, mid-Tertiary volcanic highlands to the north and east. Deep dissection by the Deschutes River and its tributaries has exposed the largest of these aprons, represented by the upper Miocene to lower Pliocene Deschutes Formation (Figure 1) and, locally, middle Miocene sediments of the Simtustus Formation and associated flood basalts. These two stratigraphic units are the focus for the field trip. Older tuffs and rhyolite domes of the Oligocene to lower Miocene John Day Formation form conspicuous topographic features in the Mutton and Ochoco Mountains that are mentioned along the course of the trip.

THE SIMTUSTUS FORMATION AND THE COLUMBIA RIVER BASALT GROUP

During the middle and late Miocene, 174,300 km^3 of basalt was extruded over a 163,700 km^2 area of eastern Washington, north-central Oregon, and western Idaho (Tolan and others, 1989). Approximately 90 volume percent of these Columbia River Basalt Group (CRBG) lava flows were extruded during the short time interval between 16.5 and 14.5 million years ago (Ma). The Deschutes basin lies just to the south and upslope of the margin of the principal flood-basalt province. Contemporaneous basalts were, however, erupted at unknown sites southeast of the basin and flowed northward through an ancestral Deschutes River valley to become intercalated with the other basalt flows farther north. Two flows of these local basalts occur in the Deschutes basin and have been assigned to the "Prineville chemical-type basalt" within the CRBG (Uppuluri, 1974; Smith, 1986c), although not all authors agree that the basalt of Prineville should be included in the CRBG (Goles, 1986; Reidel and others, 1989).

Over most of the vast region inundated by the Columbia River basalts are numerous but thin sedimentary interbeds that owe their origin, in part, to the disruption of drainage networks, locally raised base levels, and smoothing of relief resulting from flood-basalt

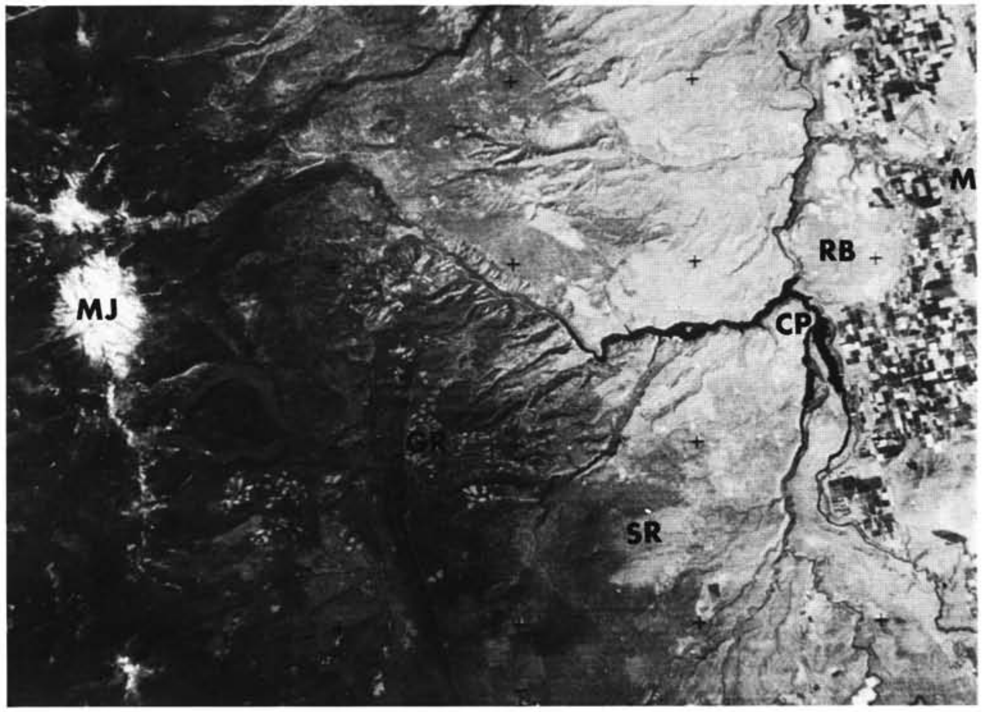


Figure 2. Landsat RBV image of part of central Oregon showing the High Cascade Range on the west and Deschutes basin on the east; crosses are spaced at approximately 10-km intervals. MJ= Mount Jefferson; GR= Green Ridge fault escarpment; SR= Squawback Ridge, late Pliocene shield volcano; CP= The Cove Palisades State Park marking the confluence of (clockwise from upper left) the Metolius, Crooked, and Deschutes Rivers; RB= Round Butte, early Pliocene shield volcano; M= Madras.

volcanism (Smith 1986b; Smith and others, 1989a). In the Deschutes basin, these sediments have been named the Simtustus Formation (Smith, 1986b). The Simtustus Formation consists of a discontinuous tuffaceous sandstone and mudstone interbed as much as 18 m thick between the two Prineville chemical-type basalt flows and an additional 5 to 65 m of similar lithologies that overlie the basalts in the Deschutes basin but appear to correlate to numerous sedimentary interbeds within younger basalts farther to the north (Smith, 1986b).

The relatively thin Simtustus Formation records modest aggradation of fluvial channels and flood plains in response to flood-basalt volcanism fed by fissure systems located 175 to 400 km east of the Cascade Range. The sediments are composed, however, principally of reworked pyroclastic debris supplied by Cascade Range volcanoes located upwind and immediately upslope to the west. The sediment is overwhelmingly dacitic and rhyodacitic in composition, although exposures of correlative rocks in the western Cascade Range are dominated by andesite and basaltic andesite lava flows (Priest and others, 1983; Smith, 1986b). This disparity reflects the preferential stripping of loose pyroclastic debris from proximal volcanic slopes and its consequent enrichment in adjacent fluvial sequences, relative to epiclastic sediment derived from the weathering of preexisting rocks.

DESCHUTES FORMATION AND THE EARLY HIGH CASCADES

Following a 5- to 7-million-year (m.y.) hiatus, alluvial aggradation recommenced in the late Miocene with emplacement of the Deschutes Formation, a lithologically diverse assemblage of volcaniclastic sediments, lava flows, pumice-fall deposits, and ignimbrites. The Deschutes Formation represents a broad apron of primary and reworked pyroclastic debris that prograded eastward from the early High Cascade Range. This precursor to the modern High Cascades was a linear volcanic chain occupying the same location as the modern arc (Figure 3) (Taylor, 1981; Priest and others, 1983). The period of magmatism from about 7.5 to 5 Ma was characterized by voluminous extrusion of basalt and basaltic andesite lava and dacitic and rhyodacitic ignimbrites (Priest and

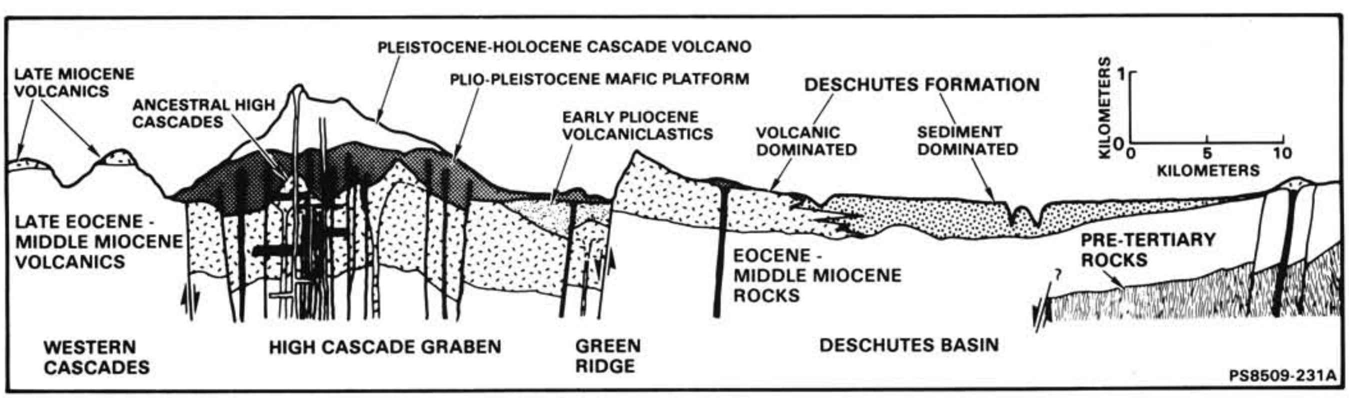


Figure 3. Generalized cross section of the central Oregon High Cascade graben and Deschutes basin. Deschutes Formation volcanic and sedimentary rocks were largely derived from the ancestral High Cascades, now buried beneath younger volcanic rocks within the High Cascade graben. Interpreted structural truncation of pre-Tertiary rocks beneath the eastern Deschutes basin is based on gravity models of Couch and others (1982) and unpublished data by R.W. Couch and R.W. Foote (Oregon State University, 1986).

others, 1983; Smith and others, 1987). The eruptive episode culminated in the collapse of the central Oregon High Cascades into intra-arc extensional basins (Taylor, 1981; Smith and Taylor, 1983; Smith and others, 1987; Smith, 1989). Green Ridge, which is located along the western margin of the Deschutes basin (Figures 2 and 3), is the eastern boundary of one of these basins. Proximal volcanic products are now buried from view beneath younger, principally mafic lava flows, leaving the Deschutes Formation as the only accessible record of this period of Cascade volcanism (Figure 3).

The Deschutes Formation ranges in thickness from about 700 m on the west to about 270 m in the center of the basin to an average of 20 m adjacent to the Mutton and Ochoco Mountains (Figure 3). Western outcrops of the Deschutes Formation are dominated by basaltic andesite and andesite lava flows representing the flanks of volcanic edifices that were truncated by the Green Ridge fault zone along the margin of the intra-arc depression (Figure 3). Basalt and basaltic andesite lava flows extended far into the Deschutes basin, where the section is dominated by coarse-grained sediments and the products of more than 100 ignimbrite-forming eruptions (Figure 3). Basalt flows were also erupted from vents within, east of, and southeast of the basin.

The sedimentology of the Deschutes Formation has been considered in detail by Smith (1986c, 1987d). Paleocurrent data and facies patterns define three depositional settings (Figures 4a and b), whose sedimentological characteristics are summarized below and whose representative sections are described at Stops 2, 4, 5, and 6.

Arc-adjacent alluvial plain

The bulk of the Deschutes Formation was deposited on a broad alluvial plain that extended approximately 50 km from the Cascades to the center and, locally, eastern portions of the Deschutes basin (Figure 4a). Although ignimbrites, pumice- and ash-fall deposits, and lava flows, which are invaluable for stratigraphic correlation, are prominent constituents of the section, this portion of the basin fill is dominated by sediments.

The arc-adjacent alluvial plain stratigraphy is primarily composed of flood and debris-flow deposits (Stops 4 and 6). Flood deposits include abundant scour-and-fill bedded sheetflood and/or shallow-braided stream facies reflecting rapid aggradation by poorly confined, flashy flows, and normally graded, massive to crudely bedded hyperconcentrated-flow deposits (Smith, 1986a; Smith and Lowe, in press). Debris-flow deposits are massive and generally matrix supported and exhibit variable grading profiles (e.g., Walton and Palmer, 1988).

The flood and debris-flow deposits are arranged in broad sheets that are bounded by erosional surfaces with as much as 80 m of relief and paleosols. Rapid aggradation of pyroclast-rich sediments and dispersal of debris-flow and hyperconcentrated-flow deposits to distances in excess of 35 km from source, which is rarely seen in nonvolcanogenic alluvium, are interpreted as responses to eruptions that provided large volumes of fragmental material and considerably altered the hill-slope hydrologic systems to generate highly varying discharges. Deposition was, therefore, largely driven by eruptive activity, and inter-eruption periods were dominated by incision as streams reestablished normal profiles in the absence of the extraordinary sediment load and discharge variability of the syneruption periods (Smith, 1987c,d, in press; Smith and Vincent, 1987). The alternation of syneruption aggradation and inter-eruption degradation produced the distinctive facies geometry of flood and debris-flow deposits that form erosively bounded sheets locally capped by paleosols (Stop 6).

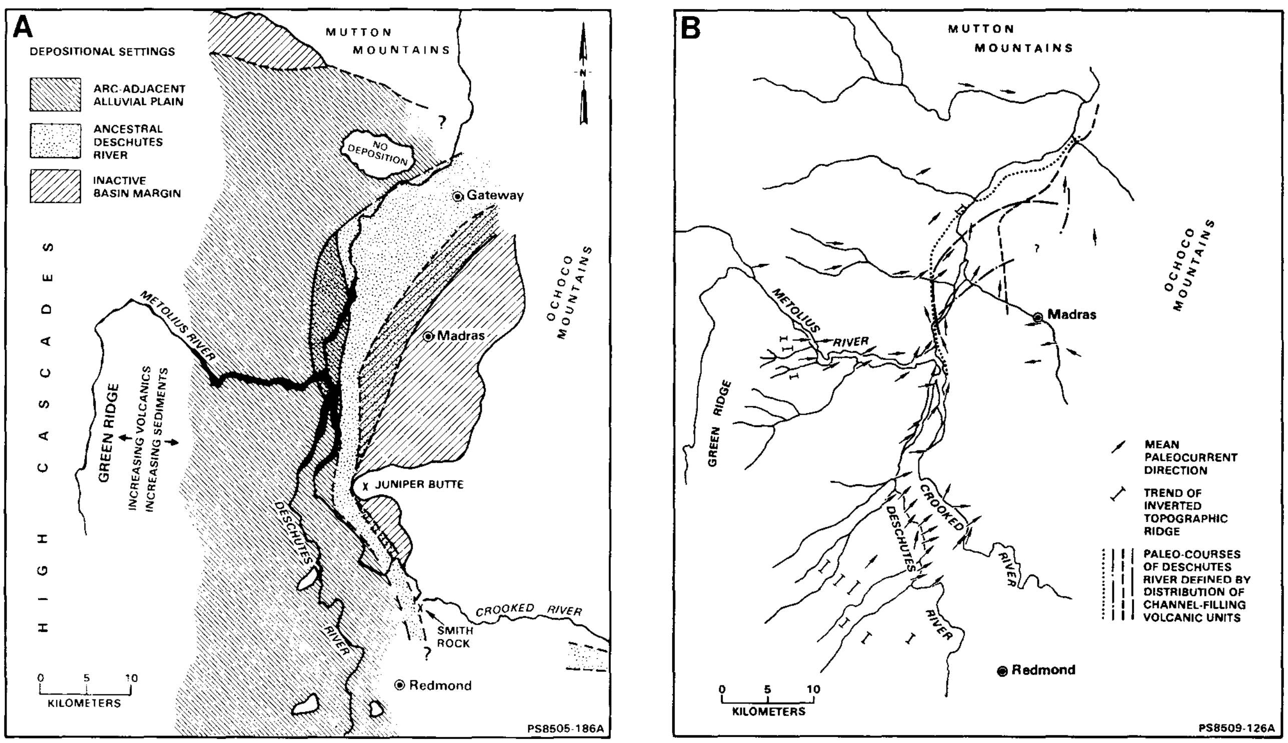


Figure 4. A. Deschutes Formation depositional settings; see text for discussion. B. Paleocurrent data for the Deschutes Formation. Arrows show mean paleocurrent directions for the localities, based on channel orientations and cross-bedding. Bars show orientations of exhumed inverted stream channels filled with resistant basalt flows. Line patterns in the northern Deschutes basin mark the paleocourse of the ancestral Deschutes River, as indicated by distribution and thickness patterns of channel-filling ignimbrites and lava flows (based on mapping by Smith, 1987a,b; and Smith and Hayman, 1987). Both figures from Smith (1987d).

More typical fluvial conditions are recorded by uncommon cobble conglomerates and associated sandstone and siltstone overbank deposits (Stop 4). These deposits are rarely more than 5 m thick and are restricted to broad valleys or channels that were incised into the more common flood and debris-flow facies. The conglomerates indicate deposition by gravel-bedload streams following incision during inter-eruption periods.

Inter-eruption aggradation is recorded only in the lower part of the stratigraphic section when basin subsidence adequately accommodated the sediment influx. The upper half of the section accumulated in only a few hundred thousand years in response to frequent, voluminous pyroclastic eruptions (Smith, 1986c; Smith and others, 1987). Accumulation outstripped the accommodation provided by modest subsidence. Hence, deposition of the upper half of the section occurred episodically only in response to volcanism, and inter-eruption periods were characterized by incision and regrading of stream profiles with little or no net deposition (Smith, 1987c, in press; Smith and Vincent, 1987; Smith and others, 1989b).

The Deschutes Formation alluvial plain was probably analogous to the ring plains associated with modern volcanoes in New Zealand (Hackett and Houghton, 1989; Smith, in press). Although the arc-adjacent alluvial plain facies association of flood and debris-flow deposits is characteristic of nonvolcanogenic alluvial fans, several observations argue against an alluvial-fan morphology for the western Deschutes basin (Smith, 1987c,d). Facies types do not vary greatly downslope, and abrupt lateral grain-size changes typical of alluvial-fan sequences do not occur in the Deschutes Formation. Paleocurrent data, largely determined from channel orientations and shoestring geometries of channel-filling lava flows and ignimbrites (Figure 4b), define a parallel to contributory drainage pattern, not the radially diverging and distributary patterns that define fans. The floods and debris flows that were generated in response to explosive volcanism episodically dispersed sediment to much greater distances than are typically seen in nonvolcanic settings where these facies are restricted to small, mountain-front alluvial fans (Smith, 1987c).

Deposition on the arc-adjacent alluvial plain virtually ceased when rapid subsidence of the intra-arc basin isolated the Deschutes basin from its Cascade Range source area (Figure 3). An abrupt transition from typical arc-adjacent alluvial plain facies to a 10- to 50-m-thick interval of superimposed sandy paleosols and pumice-fall tephras records this transition from a basin overrun with sediment and volcanic rocks to one that was virtually sediment starved (Smith, 1987d; Smith and others, 1987, 1989b). Cascade lava flows, ignimbrites, and related sediments were subsequently ponded in the intra-arc graben (Figure 3). Lava flows that do occur in the uppermost Deschutes Formation were erupted from vents within the Deschutes valley and from fissures coincident with the developing eastern faulted margin of the intra-arc depression.

Ancestral Deschutes River

The ancestral Deschutes River flowed northward at the foot of the alluvial plain (Figure 4a). Extensive progradation of the southern part of the alluvial plain forced the axial stream against older Tertiary highlands on the east margin of the basin in an area of no present-day exposure. Ancestral Deschutes River deposits are, however, found adjacent to the modern river in the northern part of the basin. Well-rounded, moderately well-sorted, and commonly cross-bedded conglomerates and coarse sandstones record a largely gravel-bedload stream. These channel deposits alternate with a nearly equal volume of bioturbated massive to thin-bedded fine sandstones and mudstones representing overbank deposition. Pumice- and ash-fall, hyperconcentrated-flow, and rare debris-flow deposits occur with the overbank facies. Details of this facies association are described at Stop 2.

Inactive basin margin

Deposition in the Deschutes basin was principally in response to Cascade volcanism that dispersed sediment eastward across most of the basin. Small watersheds did drain southward from the Mutton Mountains and westward from the Ochoco Mountains (Figure 4a). Deschutes Formation sediments exposed in and east of Madras are the most representative of this setting and consist of two components. The bulk of the sediments is composed of poorly sorted, angular gravel and sand derived from older Tertiary rocks of the Ochoco Mountains: mainly John Day Formation rhyolite clasts and, rarely, clasts of the basalt of Prineville. The second component is vitric pyroclastic debris of Cascade provenance derived from the reworking of ash-fall and pumice lapillistones that occur locally within the section. Sediment accumulation along these relatively inactive margins of the basin was very slow. The Deschutes Formation sections in these areas rarely exceed 20 m in thickness and exhibit abundant evidence of pedogenic disruption throughout, in the form of abundant burrow and root bioturbation and oxidation of the sediment to brown and orange colors (Stop 5).

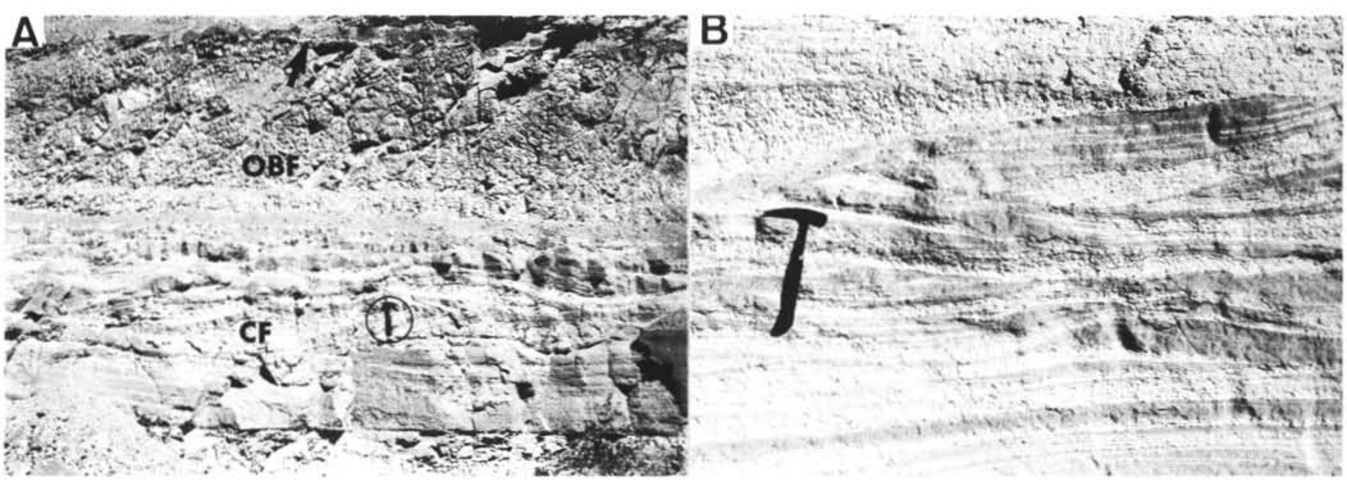


Figure 5. Views of outcrops of the Simtustus Formation at Pelton Dam, Stop 1. A. Typical fining-upward sequence of trough cross-bedded channel facies (CF) and massive, blocky overbank facies (OBF). Arrow near top of photo points to base of accretionary-lapilli fallout tuff within the overbank deposits. B. Close view of trough cross-beds showing alternations of dark lithic-feldspathic sand and light tuffaceous silt suggesting unsteady flow during deposition.

DIRECTIONS TO STOP 1

The field guide for day one (Stops 1 through 5) begins at the intersection of U.S. Highways 97 and 26 at the north edge of Madras. Proceed northwestward on westbound U.S. 26 for 9.7 mi to the intersection with an unnamed road on the left (south side of Highway 26) that leads to Pelton Dam and Lake Simtustus. Turn left onto this road and continue 2.8 mi to Stop 1, at the eastern abutment of Pelton Dam.

GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 1

Highway 26 climbs from Madras onto the Agency Plains. Sandstones of the Deschutes Formation occur in the road cuts near the junction with U.S. 97. The Agency Plains are underlain by a thin erosional remnant of Deschutes Formation sediments that rest on a 5.3-Ma basalt flow that originated at Tetherow Butte, about 40 km to the south of here near the village of Terrebonne. This basalt, with spectacular columnar joints, is well exposed where Highway 26 begins its steep descent to the Deschutes River. Road cuts along the grade in Campbell Canyon expose sedimentary facies of the Deschutes Formation. After turning off toward Pelton Dam, the road follows the top of the basalt of Prineville, affording views of road cuts in the overlying Simtustus Formation, before descending through the uppermost lava flow near Stop 1.

STOP 1. SEDIMENTARY FEATURES OF THE SIMTUSTUS FORMATION

Pelton Dam is constructed against the lower of two thick flows of the basalt of Prineville. The upper flow and the intervening sedimentary interbed, assigned to the Simtustus Formation, are exposed in the adjacent road cuts. Although consisting almost entirely of pyroclastic fragments, the Simtustus Formation sediments closely resemble fluvial facies typical of nonvolcaniclastic alluvium. The base of the Simtustus Formation is a reworked tuff with abundant leaf fragments (Pelton flora of Ashwill, 1983), which crops out below the road. The remainder of the section is composed of fining-upward sequences of tuffaceous, cross-bedded volcanic sandstone and massive tuffaceous mudstone (Figure 5a). A fine conglomerate occurs immediately below the overlying basalt flow. Fining-upward sequences are typical of the Simtustus Formation within the central Deschutes basin and record a north-northeast-flowing, laterally shifting, mixed-load stream. Trough crossbeds contain many internal lenses of tuffaceous silt, suggesting very unsteady flows (Figure 5b). The massive pink to light-brown overbank deposits contain abundant dispersed pumice lapilli. In some respects, they superficially resemble unwelded ignimbrites because of their massive, pumice-rich character. Instead, they represent bioturbated fine-grained sediment that included hydrodynamically equivalent pumice and, in some case, pumice- and ash-fall deposits. The gradational bases to underlying structured sediment, rare preservation of original depositional features, and local abundance of plant seeds and vertebrate fossils (not seen here) are important features that allow distinction from texturally similar ignimbrites. A continuous brown layer (20 cm thick) within the pink overbank facies is a normally graded ash-fall deposit with numerous accretionary lapilli near its base (Figure 5a). The abundance of lithic fragments and fine-grained, angular ash shards along with accretionary lapilli suggest that this ash-fall was the result of a powerful phreatomagmatic eruption.

DIRECTIONS TO STOP 2

Continue southward from Pelton Dam and follow the road on its winding route up and out of the Deschutes Canyon until it terminates at Belmont Lane, about 6 mi from Stop 1. Turn right (west) on Belmont Lane and proceed 2.1 mi to the entrance to Round Butte Dam. Continue to the project office, where inquiry should be made to visit the locality of Stop 2, which is represented in road cuts between the dam and the lower gate south of the office.

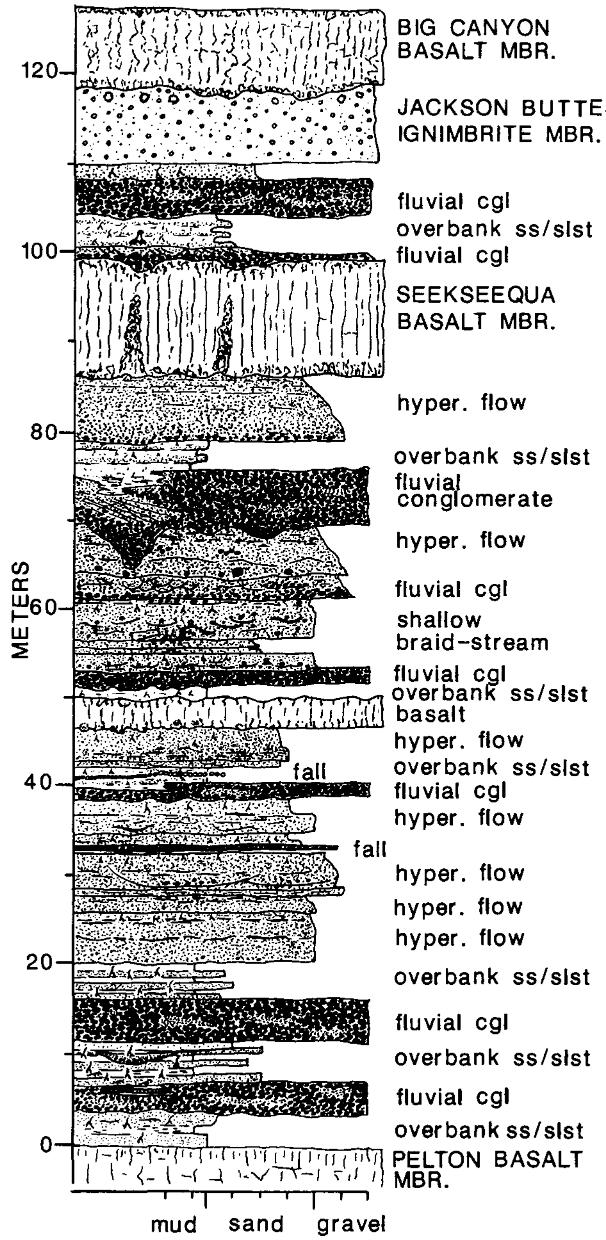


Figure 6. Graphic measured section of the lower Deschutes Formation at Round Butte Dam, Stop 2. Ancestral Deschutes River sediments consist of conglomerates and related flood-plain sandstones and siltstones alternating with hyperconcentrated-flow deposits and less common flows and ignimbrites. Scour-and-fill bedded pebbly pumiceous sands suggesting flashy-discharge, shallow braided stream deposition occur at 55-60 m; this facies is more typical of the arc-adjacent alluvial plain setting and may have been deposited by a tributary to the main river. Cgl = conglomerate; ss/slst = sandstone/siltstone; hyper = hyperconcentrated.

GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 2

Road cuts south of Pelton Dam expose the basalt of Prineville and the Deschutes Formation. Excellent outcrops of the Deschutes Formation are visible in Willow Creek Canyon, about 2 mi beyond Pelton Dam. Landslides are common along the Deschutes Canyon; slope stability problems have forced the closure of the once popular

Pelton Park. Round Butte, a 3.9-Ma basaltic shield volcano (Snee, personal communication, 1985; Smith, 1986c) surmounted by a small cinder cone, looms to the southwest of the intersection of Elk Drive and Belmont Lane.

STOP 2. ANCESTRAL DESCHUTES RIVER FACIES, DESCHUTES FORMATION

Road cuts along the east wall of the Deschutes River at Round Butte Dam provide the best exposures of Deschutes Formation deposits near the axis of the basin. The thick basaltic cliffs on the west side of the river are 1.2-Ma lava flows (Snee, personal communication, 1985; Smith, 1986c), that were erupted approximately 85 km south of here and flowed through the Crooked and Deschutes River canyons to a terminus represented by the bench that the utility project office is built on. The base of the canyon is cut into the Pelton basalt member of the Deschutes Formation, which has been dated at 7.42 ± 0.22 Ma (Snee, personal communication, 1985; Smith, 1986c). Based on stratigraphic correlations and isotopic dates (Smith, 1986c), that part of the section illustrated in Figure 6 is thought to represent about 1.6 m.y.

The late Miocene Deschutes River is represented by sandy conglomerate channel-fill facies and sandy and muddy overbank deposits (Figure 7a) that are intercalated with pyroclastic-fall units and hyperconcentrated-flow facies. The conglomerates are principally composed of well-rounded Cascade-derived volcanic clasts with varying proportions of John Day Formation rhyolite clasts brought from the Ochoco Mountains. Crude stratification, lenticular channel forms, and discontinuous cross-bedded and plane-bedded sandstone lenses are all typical of gravel-bedload stream deposits (e.g., Miall, 1977).

The channel facies merge laterally with flood-plain deposits consisting primarily of interbedded fine-grained sandstone, siltstone, and minor claystone in tabular, commonly normal-graded beds with sharp, undulating bases. Depositional structures in the overbank materials are partly to completely obliterated by bioturbation, but trough cross-bedding and ripple cross-lamination are locally preserved. Isolated channel fills of coarse-grained pebbly sandstone mark the probable courses of chute channels that were occupied during floods. Root traces and local stumps are lined with silica and light-colored clay and, with occasional burrows, reflect bioturbation in the flood-plain environment.

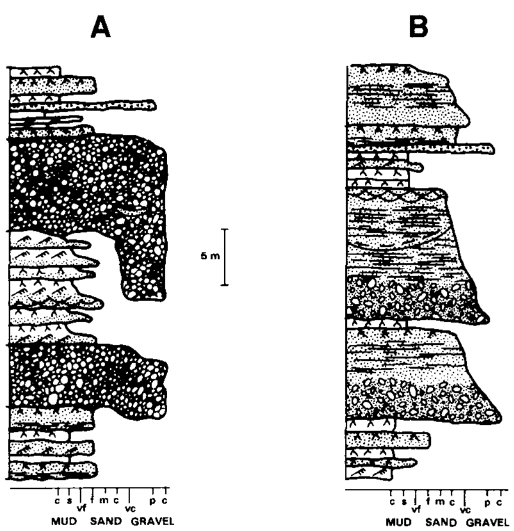


Figure 7. Schematic representations of the two common facies assemblages seen along the depositional tract of the ancestral Deschutes River. A. Alternating sandy conglomerates and bioturbated graded sandstones and siltstones record channel and overbank facies associated with a channelized gravel-bedload stream. B. Some overbank sequences include graded-stratified hyperconcentrated-flow facies deposited across flood plains during large-volume, sediment-laden floods, probably related to eruption-induced debris flows that crossed the alluvial plains to the southwest and were diluted to hyperconcentrated flows by mixing with ancestral Deschutes River water.

Numerous bioturbated or partly reworked pyroclastic-fall deposits occur as continuous layers of white pumice lapilli and ash that drape irregularities on depositional surfaces. These deposits are found only with overbank facies, reflecting the relatively stable surficial setting necessary for preservation.

Also occurring with overbank deposits or at vertical transitions from channel to overbank facies are hyperconcentrated-flow deposits (Figures 7b, 8). Hyperconcentrated flows represent a sediment transport condition that is intermediate between normal, dilute stream flows and viscous debris flows (Smith, 1986a; Smith and Lowe, in press). Sediment is deposited rapidly from high-concentration dispersions and sorted by limited tractive transport under waning-flow conditions. The resulting coarse sandstones and pebbly sandstones seen here range in thickness from 0.7 to 8.0 m and typically consist of a massive base that fines upward into a crudely bedded upper part (Figure 8). Scour surfaces occur between depositional units, but internal scours and cross-bedding are rare to absent. Pumice lapilli, if present, are typically concentrated near the top of the bed. The occurrence of hyperconcentrated-flow deposits with overbank facies (Figure 7b) reflects the high discharges and large volumes of the causative floods. The restriction of this facies to overbank environments results from its reworking where initially deposited in channel settings. Hyperconcentrated-flow deposits are thickest and most abundant within the ancestral Deschutes River deposits, probably representing the genesis of these flows by dilution of large debris flows that crossed the arc-adjacent alluvial plain (Stops 4 and 5) as they entered the channel of the larger stream.

The prominent columnar-jointed basalt near the top of the grade is the Seekseequa basalt member (Smith, 1986c). The lava flow is one of three basalts and one ignimbrite unit that filled and overflowed the ancestral Deschutes River channel (dotted course in Figure 4b). Lateral tracing of these units permits determination of the dimensions and course of the channel that was filled. The main channel at the time of eruption of the Seekseequa basalt was located 2 km to the west of here, was 10 m deep and 50 m wide, and flowed toward the north-northeast. At this location, the basalt rests on a thick hyperconcentrated-flow unit that formed the top of a terrace adjacent to the channel. Erosion along the top of the basalt and overlying conglomerate record the repositioning of the channel following the emplacement of the lava flow.

At the top of the illustrated section (Figure 6) near the gate is a pink ignimbrite, informally named the Jackson Buttes ignimbrite member (Smith, 1986c). The dispersal of moderately rounded to rounded pumice lapilli in a massive, crystal-rich, ashy matrix is the typical appearance of unwelded ignimbrites. Pink and orange colors are common and result from high-temperature oxidation of iron within glass and mineral grains during fumarolic activity following emplacement. Pumice lapilli in the Jackson Buttes ignimbrite are white and light-gray in color, reflecting compositional heterogeneity of the erupted magma ranging from rhyodacitic to rhyolitic (Smith, 1986c).

Despite the apparently uniform medium- to dark-gray color of most medium- to coarse-grained sandstones in this section, the composition of the sediments is quite variable. Sandstones associated with the conglomerates consist primarily of basalt and basaltic andesite lithic fragments with groundmass textures and crystals of plagioclase, olivine, and occasional clinopyroxene. These sands are, therefore, primarily composed of epiclastic fragments eroded from mafic lava flows, which are the dominant component

Figure 8. Graded-stratified hyperconcentrated-flow deposit resting on light-colored, bioturbated overbank facies (~78- to 84-m interval shown on Figure 6). Note concentration of cobbles at the base of the unit and upward increase in definition of horizontal stratification as grain size decreases to medium-coarse sand.

of the Deschutes Formation on Green Ridge located closer to the Cascade Range source area. The hyperconcentrated-flow deposits, on the other hand, consist almost entirely of vesicular glassy pyroclasts and free crystals of complexly zoned plagioclase, clinopyroxene, and orthopyroxene. This mineralogy is typical of many of the dacitic and rhyodacitic ignimbrites in the Deschutes Formation, many of which contain mostly dark-brown to black ash and pumice (e.g., Peninsula ignimbrite member at Stop 6). Hyperconcentrated flows, therefore, consist mostly of pyroclastic debris and probably occurred directly or indirectly in response to eruptions that generated large volumes of loose pyroclasts. The fluvial conglomerates and related sandstones, on the other hand, were not deposited as responses to volcanism and contain a greater percentage of epiclastic fragments.

DIRECTIONS TO STOP 3

Return to Belmont Lane and turn right (south) on Mountain View Road, 0.5 mi beyond the Round Butte Dam gate. Follow Mountain View Drive for 6.25 mi to Stop 3 at a marked viewpoint over the Crooked River at The Cove Palisades State Park.

GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 3

Mountain View Drive climbs onto the Round Butte shield volcano and then descends its south flank and traverses basalt flows in the upper Deschutes Formation erupted from both Cascade and intrabasinal sources. From near the south base of Round Butte are good views to the southeast of the western end of the Ochoco Mountains (Figure 1). The prominent mesas and small peaks are largely underlain by uplifted rhyolitic ignimbrites and lava flows of the John Day Formation (Robinson and Stensland, 1979). The westernmost of these topographic features, Juniper Butte, is a large rhyolite dome.

STOP 3. THE COVE PALISADES STATE PARK: OVERVIEW OF THE DESCHUTES BASIN AND CENTRAL OREGON HIGH CASCADES

The Cove Palisades State Park marks the confluence of the Deschutes, Crooked, and Metolius Rivers, which have been impounded behind Round Butte Dam to form Lake Billy Chinook (Figures 1 and 2). Sediments, ignimbrites, and lava flows of the Deschutes Formation are well exposed in road cuts and in natural canyon-wall exposures. Pleistocene basalt flows also seen at Stop 2 form conspicuous, 150-m-high columnar-jointed basalt cliffs at The Island (Figure 9), which separates the Deschutes and Crooked Rivers. They are also exposed along the Crooked River upstream of the bridge as erosional remnants that rest against the Deschutes Formation along profoundly disconformable contacts.

Deschutes Formation outcrops at The Cove represent arc-adjacent alluvial plain facies interbedded with basalt flows and dacitic to rhyolitic ignimbrites. The ancestral Deschutes River was located to the east of the present canyons. About 200 m of Deschutes Formation crops out above the level of the lake, but the section represents only a relatively short time period between about 5.6 Ma and 5.3 Ma (Snee, personal communication, 1985; Smith, 1986c). This was a period of voluminous extrusions in the ancestral Cascade Range, which was located in the same general location as the modern peaks that are visible from this point. Rapid subsidence of the central Oregon High Cascade graben began at about 5.4 Ma (Smith and others, 1987). The eastern margin of the depression is marked by Green Ridge, a 700-m-high topographic escarpment whose forested crest and dip slope can be traced southward from a point in front of snow-capped Mount Jefferson to the forested cone of Black Butte (Figures 2 and 9). At least 1 to 2 km of structural relief was formed across the Green Ridge fault zone and terminated the transport of volcaniclastic debris from the Cascade axis to the Deschutes basin. This material accumulated instead within the intra-arc basin to form at least 2 km of lacustrine and fluvial sediments and tuffs that are locally exposed along the west base of Green Ridge, where they have been informally named the Camp Sherman beds (Figure 3) (Smith, 1986c). Basalt and basaltic andesite lavas were erupted from vents along the Green

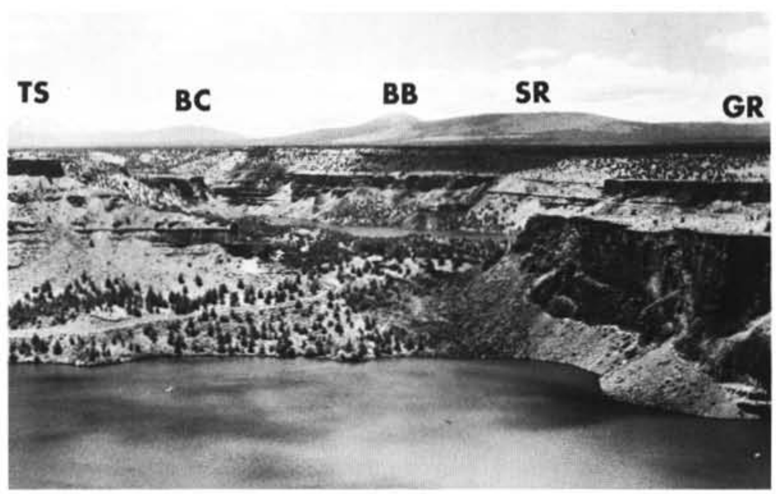


Figure 9. Westward view from Stop 3 across The Cove Palisades State Park to the crest of the High Cascades. Crooked River arm of Lake Billy Chinook in foreground; Deschutes River arm in rear. Road in center of view passes between Deschutes Formation outcrops of The Ship (on the left) and early Pleistocene intracanyon basalt composing The Island (on the right). Other erosional remnants of the intracanyon lavas form dark, flat-topped outcrops above the Deschutes River. Prominent features along the skyline include the Three Sisters (TS), Black Crater (BC), Black Butte volcano (BB) at the south end of Green Ridge (GR), and Squawback Ridge (SR).

Ridge fault zone and became the last volcanic units to flow eastward into the Deschutes basin. These lavas form the rimrock on the west side of The Cove and, on the east side, are intercalated with basalts erupted within the basin.

DIRECTIONS TO STOP 4

Continue south on Mountain View Road for 0.7 mi to its intersection with an unnamed road leading into The Cove Palisades State Park. Turn right and proceed 6.8 mi across both the Crooked and Deschutes Rivers to Stop 4a. Parking is available on the east side of the road, just above the second switchback. Stop 4b is at the top of the highway grade an additional 1.1 mi to the west. These stops involve viewing of road cuts along the steep, winding road that climbs the west wall of the Deschutes Canyon. Considerable caution should be exercised in selecting a safe parking place, and a watchful eye for traffic is necessary while examining the outcrops.

GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 4

A variety of Deschutes Formation lithologies are exposed along the highway within the state park. The quarry near the east entrance is developed in the Agency Plains basalt flow of the Tetherow Butte member. This is one of two lavas that flowed as far as 60 km from a vent complex at Tetherow Butte, 26 km to the south of here. The Tetherow Butte lavas are the most extensive of those erupted within the Deschutes basin during the same period as the principal collapse of the High Cascades. Two ignimbrites and a variety of sediments are exposed along the road that descends and follows along the Crooked River. A parking area at The Ship (Figure 9) between the Deschutes and Crooked Rivers is adjacent to outcrops of Deschutes Formation sediments and ignimbrites, including the prominent white Cove ignimbrite member that will be examined at Stop 4a.

STOP 4. ARC-ADJACENT ALLUVIAL PLAIN FACIES OF THE DESCHUTES FORMATION: THE COVE PALISADES STATE PARK

Road cuts above the Deschutes River provide an opportunity to examine arc-adjacent alluvial plain facies of the Deschutes Formation. Two parts of the section will be examined.

Stop 4a

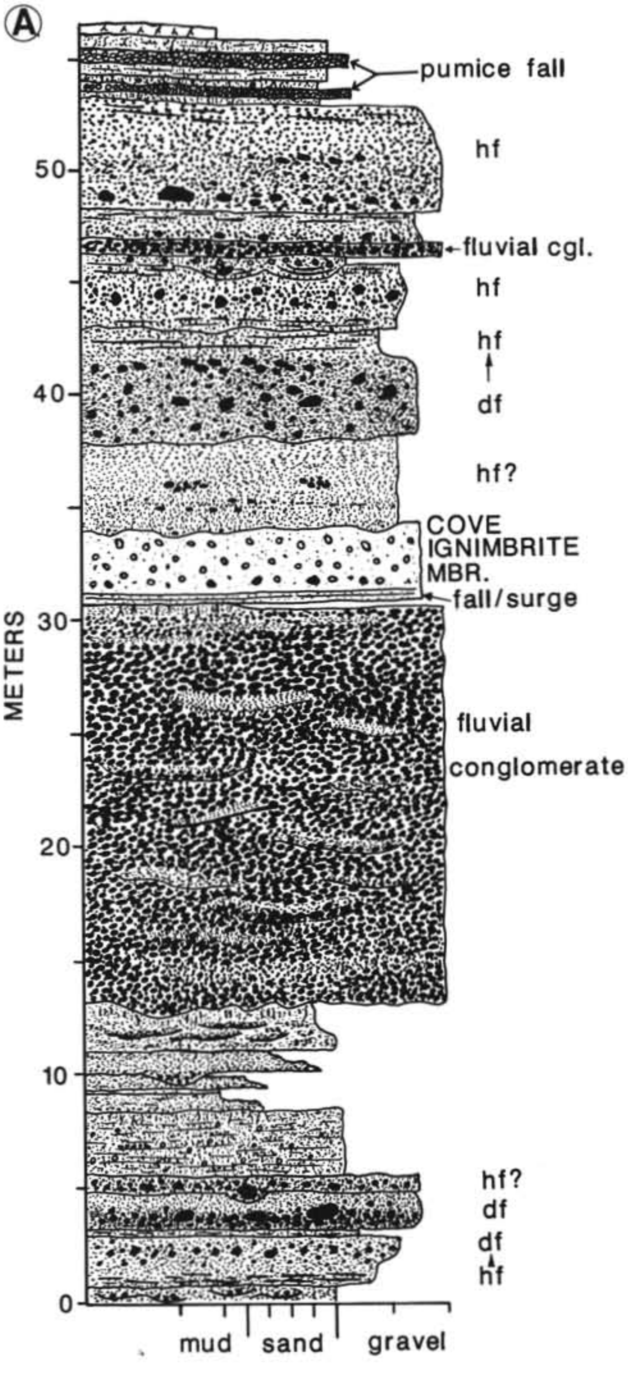
The section illustrated in Figure 10a for Stop 4a begins about 15 m below the second switchback and extends upward to a level about even with the prominent intracanyon basalt bench. Erosional remnants of the Jackson Buttes ignimbrite member can be seen enclosed in gravel just above the first switchback; therefore, the stratigraphic interval examined here is slightly higher than that seen at Stop 2.

Near the center of the section shown in Figure 10a and directly opposite the parking area is a fluvial conglomerate similar to conglomerates seen at Stop 2. This conglomerate, however, is restricted to a 15- to 20-m-deep and about 300-m-wide valley whose margins trend N. 40° E. to N. 70° E. through the park and record an east-flowing stream. This conglomerate contains only Cascade clasts and lacks the associated well-developed flood-plain deposits that characterize the ancestral Deschutes River deposits; the latter feature is probably a result of the restricted dimensions of the valley. The conglomerate records inter-eruption, normal fluvial sedimentation within a small valley incised into syneruption flood and debris-flow deposits. This is the stratigraphically highest such gravel known. Above this level, intervals of syneruption flood and debris-flow deposits are separated by erosion surfaces with little or no associated normal-streamflow gravel. The younger deposits accumulated only in response to volcanism-induced sediment loads and were not adequately accommodated by basin subsidence to permit aggradation by inter-eruption graded streams (Smith. 1987d, in press).

The section exposed below the conglomerate includes two volcanic debris-flow deposits (Figure 11). These flows are composed of Cascade material that originated 35 km to the west. The upper deposit is about 1.5 m thick and is a massive, inverse-to-normal-graded unit with clasts up to 0.75 m across supported in a matrix of sand and silt. Close examination of the fine-grained matrix shows the presence of small vesicles caused by air trapped in the viscous water-sediment mixture during transport; these are relatively common features of both volcanic and nonvolcanic debris-flow deposits and should not be taken as indication of the presence of a high-temperature vapor phase (Smith and Lowe, in press). The abundance of rounded clasts suggests that this debris flow bulked material from the streambed during transit (Scott, 1988; Smith and Lowe, in press). A thin sandstone separates this deposit from that of the lower debris flow. This deposit is about 1.8 m thick and contains more angular clasts reaching maximum dimensions of only 15 cm. The matrix of this unit is very sandy and lacks the abundant silt seen in the higher debris-flow deposit. The upper two-thirds of the bed has a typical massive, debris-flow texture but grades downward into a slightly better sorted, finer grained, and crudely stratified basal zone (Figure 11). Vertical variations of this type are the record of successive passage of genetically related hyperconcentrated and debris flows, the former generated from the latter by dilution through addition of stream water (Pierson and Scott, 1985; Smith, 1986a, 1987d; Scott, 1988; Smith and Lowe, in press). A hyperconcentrated-flow deposit at this stratigraphic position, 3.5 km down the paleoslope to the northeast, may record the complete dilution of this debris flow to hyperconcentrated flow. Mud-rich debris flows are less susceptible to dilution to hyperconcentrated flows than are those with granular matrices (Scott, 1988). This may be one factor that accounts for the lack of a hyperconcentrated-flow deposit beneath the higher debris-flow unit.

Above the conglomerate is the Cove ignimbrite member (Figure 10a) (Smith, 1986c), the most conspicuous pyroclastic-flow deposit at The Cove. The 3.2-m-thick white ignimbrite contains rhyodacitic pumice lapilli up to 8 cm in diameter and a variety of accidental or accessory lithic fragments up to 20 cm across that occur mostly near the base of the unit. The ashy matrix of the ignimbrite contains a great abundance of plagioclase crystals that were concentrated in the matrix as fine ash was elutriated from the fluidized flow during transport (Walker, 1971). About 70 cm of bedded pyroclastics occur beneath the ignimbrite. From bottom to top this unit includes (1) 50 cm of coarse ash, fine lapilli, and abundant accretionary lapilli; (2) 2 cm of pumice lapilli and angular lithic fragments up to 4 mm across; (3) about 15 cm of ash; and (4) a discontinuous, lenticular unit of plane-bedded and low-angle cross-bedded ash. The first three layers exhibit uniform mantle bedding typical of fall units; the fourth layer is interpreted as a ground-surge deposit generated by ingestion of ambient air at the head of the pyroclastic flow and better developed beneath the Cove ignimbrite at other localities. The variable textures of the fall layers beneath the ignimbrite reflect complexities of the eruption.

An erosion surface truncates the upper part of the tuff here and cuts down through all of it toward the north. Stratigraphic studies in this area show that at least 10 m of sediment deposited above the Cove ignimbrite member have also been removed here. A remnant of these scour-and-fill bedded, shallow braided-stream and sheetflood deposits capped by an oxidized massive sandstone paleosol crops out along the road about 15 m to the south (not shown on Figure 10a). The paleosol probably formed after the erosion surface developed, leaving high areas on the surface as relatively stable areas, while deposition was occurring along channels and valleys at lower elevations. Most of the arc-adjacent alluvial plain stratigraphy consists of depositional packages bounded by



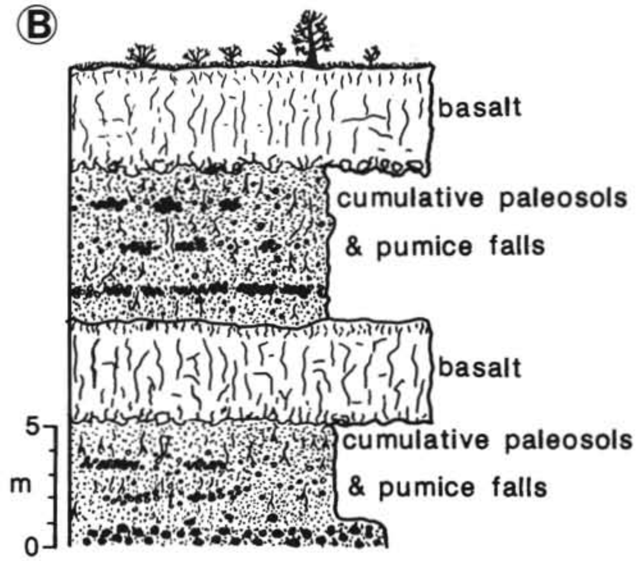


Figure 10 (left and above). Graphic measured sections of the Deschutes Formation near the west entrance to The Cove Palisades State Park, Stop 4. A. Section along road at Stop 4a; designated parking area is at approximately the 20-m level. See text for discussion of critical features. hf = hyperconcentrated flow; df = debris flow. B. Section along road at top of the Deschutes arm grade at Stop 4b showing basalt flows intercalated with pedogenically modified sandstones and lapillistones typical of the upper part of the alluvial-plain section.

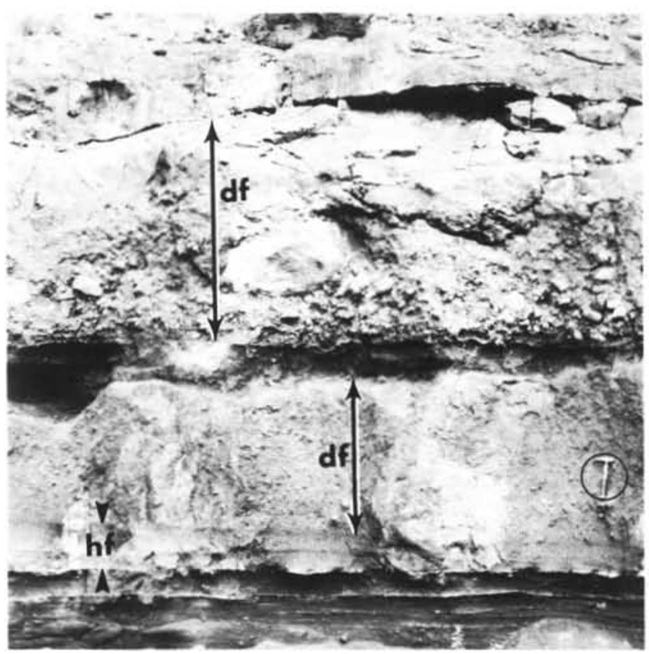


Figure 11. View of debris-flow deposits (df) at 1- to 5-m interval of section shown in Figure 10a (Stop 4a). Note stratified hyperconcentrated-flow deposits (hf) underlying the lowest debris-flow deposit. See text for discussion.

erosion surfaces; the complexity of the stratigraphy, therefore, is not easily evaluated in vertical sections but requires careful lateral tracing of volcanic marker units, erosion surfaces, and paleosols along the canyon walls.

The remainder of the section illustrated in Figure 10a is a sequence of poorly sorted, massive to crudely stratified conglomerates (Figure 12). None of these conglomerates is as well sorted or stratified as the normal fluvial conglomerates seen below the Cove ignimbrite or at Stop 2. Some beds have abundant fine-grained matrix and are probably debris-flow deposits. Most of these conglomerates, however, conspicuously lack sub-1-mm grains, are commonly normal graded and crudely stratified, and exhibit clast fabric that is relatively simple and nonrandom; these characteristics suggest deposition from hyperconcentrated flows (Smith, 1986a; Smith and Lowe, in press). Thin scour-and-fill bedded pebbly sandstones intervene between some of these units and represent deposition by shallow, flashy discharge braided streams. This part of the section is capped by 3.5 m of bioturbated, relatively thin-bedded sandstones and pumice-fall lapillistones recording diminished sedimentation rate and

Figure 12. Poorly sorted debris-flow and hyperconcentrated-flow deposits overlying Cove ignimbrite member at Stop 4a.

stability at this location, which correlates to a period of incision recorded by paleochannels to the north.

Stop 4b

Stop 4b, at the top of the highway grade, provides exposures that are typical of the upper part of the arc-adjacent alluvial plain sequence throughout the basin (Figure 10b). The two basalt flows exposed here have been traced westward to Green Ridge, where they occur in the upper part of the section that postdates the initial development of relief across the Green Ridge fault zone (Conrey, 1985; Smith and others, 1987). Facies like those seen at Stop 4a and those that will be seen at Stop 6 are abruptly overlain across the entire alluvial plain by volcaniclastic materials of the type seen here in association with the basalt flows. Massive light-brown to orange sandstones (Figure 13) contain abundant rodent burrows, locally well-preserved root traces, and iron-oxide and clay rims around framework grains that account for the light color. These are paleosols developed cumulatively within thin depositional units of coarse-grained sand. Pumice-fall deposits, greatly disturbed by burrows (Figure 13), were emplaced with these sands, and pedogenic mixing of pumice lapilli and oxidized sand creates a "pseudo-ignimbrite" texture in the final deposit. These pedogenically modified sandstones and lapilli stones record the end of volcanism-induced aggradation in the basin and the onset of a period of landscape stability over most of the basin. Abundant pumice-fall beds, some as much as 2 m thick, record continued explosive volcanism in the Cascades, but no ignimbrites or flood and debris-flow sediments resulting from rapid stripping of pyroclastic debris from steep proximal slopes occur in this uppermost part of the section. These relationships are interpreted as the stratigraphic record of an intra-arc graben development. Subsequent arc-axis-erupted pyroclastic flows, lava flows, and products of eruption-related sedimentation events were trapped within the intra-arc basin, thereby starving the adjacent Deschutes basin from the sources of material that had accumulated there during the previous 2.5-m.y. period (Smith and others, 1987).

The high-alumina olivine basalts exposed at Stop 4a have diktytaxitic textures that are characteristic of most basalts within the Deschutes basin and within the Basin and Range province of southeastern Oregon (Hart and others, 1984). The texture is defined by the high density of small angular vesicles developed between unusually coarse groundmass plagioclase laths and results from rapid extrusion of relatively volatile-rich basalt that continues to vesiculate after a large degree of extratelluric crystallization is complete. Vesicle cylinders and pipe vesicles are common features of these flows. The cylinders are usually vertical and represent zones of diapiric rise of gas-rich melt (Goff, 1977) after the flow has come to rest. The pipe vesicles are restricted to the base of the flow and are generated by the rise of steam from a damp substrate. Pipe vesicles form as the flow is moving and are bent over in the direction of flow movement (Waters, 1960), providing measures of paleoslope orientation that, in this case, is inclined eastward.

DIRECTIONS TO STOP 5

Retrace the route through The Cove Palisades State Park and follow signs to U.S. 97 and Madras. Proceed northward into Madras to the intersection with C Street; turn right (east). At about 0.6 mi, bear right on Grizzly Road. Continue for 1.8 mi and turn right (south) on the road leading to the county landfill. Park carefully on the shoulder at about 0.2 mi beyond the junction. The outcrops of interest at Stop 5 are about 20 m above the east side of the road.

GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 5

Between The Cove Palisades State Park and U.S. 97, the route crosses remnants of Deschutes Formation sediments that were deposited following emplacement of the rimrock basalts at the park and before the formation of Round Butte. At least 50 m of sediment similar to facies seen at Stop 4b accumulated during a 1.4-m.y. period, but lateral planation by streams has removed all but a few meters of this section except near Round Butte. Road cuts leading into Madras consist largely of brown, oxidized, and pedogenically modified conglomeratic sandstones and lapilli stones typical of the inactive basin margin depositional setting of the Deschutes Formation (Figure 4a). Brightly colored rhyolite clasts, derived from the John Day Formation east of the Deschutes basin, are visible in these road cuts. Similar deposits are examined at Stop 5.

Figure 13. Pedogenically disturbed sandstone and lapillistone at Stop 4b. Pumice-fall deposit to left of hammer grades into bioturbated pumiceous sandstone on right. Note rodent burrow at tip of hammer point and opalized root traces marked by arrows at bottom of photo.

STOP 5. INACTIVE BASIN MARGIN DEPOSITS OF THE DESCHUTES FORMATION, EAST OF MADRAS

Exposures here are typical of late Miocene sedimentation along the inactive northern and eastern margins of the Deschutes basin. Deschutes Formation lithologies extend only 2 km east from this point and onlap constructional and structural topographic highs composed of Oligocene John Day Formation. Composite exposures suggest that the section is less than 60 m thick in this area. The basalt flow capping the ridge to the east was erupted from a small shield volcano along the margin of the Ochoco Mountains, 15 km to the southeast of here, near the end of Deschutes Formation deposition.

The brown hues of the sandstones suggest pedogenic oxidation, as seen at previous stops. This interpretation is further supported by the paucity of preserved depositional structures, the abundance of insect and rodent burrows (Figure 14), and petrographic observations of oxidized clay coatings on framework grains (Smith, 1986c). John Day Formation ignimbrite clasts comprise the bulk of the sediment here (Figure 14), consistent with deposition by streams draining the Ochoco Mountains rather than the Cascades. Light-colored layers are distal ash- and pumice-fall tephras (Figure 14) derived from High Cascade volcanoes; Cascade pyroclastic debris also was reworked and admixed with epiclastic sediment to form the sandstones. Pedogenic disruption of the sediment, which is seen at all stratigraphic levels wherever the Ochoco- and Mutton Mountain-derived facies are exposed, reflects low sedimentation rates associated with these margins of the basin compared to the much higher and very episodic rates of deposition on the arc-adjacent alluvial plain to the west. The strong asymmetry of sediment volume and lack of basin-defining structures are clear indications of a primary volcanic, rather than subsidence-driven, mechanism for deposition and preservation of the Deschutes Formation.

Figure 14. Light-colored pumice- and ash-fall deposit separating massive pedogenically modified sandstones and conglomerates characteristic of the inactive basin margin facies assemblage southeast of Madras at Stop 5. Arrows point to rodent burrows in and above pumice lapillistone. Insect burrows with meniscate fills can be found within the pyroclastic-fall bed and below it in the blocky textured, oxidized sandstone.

Three different occurrences of paleosol sandstones are illustrated by Stops 4 and 5. Paleosol sandstones of the first type, at Stop 4a, are relatively thin (1 to 3 m) intervals of pedogenically disrupted sandstone that mark the tops of aggradational packages of syn-eruption flood and debris-flow facies, which are elsewhere bounded by erosion surfaces. Pedogenesis occurred on stable, relatively high-standing and well-drained parts of the landscape above incised inter-eruption channels. Paleosol sandstones of the second type, seen at Stop 4b, are thick (10 to 50 m) paleosols that are stratigraphically restricted to the upper part of the arc-adjacent alluvial plain section. These cumulic paleosols record an abrupt decrease in sedimentation rate resulting from structural isolation of the basin from its primary sediment source. Those of the third type, at Stop 5, represent the entire stratigraphic interval of the Deschutes Formation but are spatially restricted to the northern and eastern basin margins, where cumulic soil formation was a consequence of slow sediment accumulation in a depositionally inactive setting.

This is the end of day one of the SEPM field trip. The guide for day two (Stops 6 and 7) begins at Ogden Wayside State Park located on U.S. 97, 18.5 mi south of Madras (8.4 mi north of Redmond).

DIRECTIONS TO STOP 6

Start at Ogden Wayside State Park located on the west side of U.S. 97 between Madras and Redmond, where the highway crosses the Crooked River. The overlook here features views of the 105 m-thick Pleistocene basalts that filled the ancestral Crooked River canyon; these are the same flows as seen at Stops 2, 3, and 4. Deschutes Formation basalts, tuffs, and sediments crop out on the north side of the canyon, east of the highway bridge.

Proceed 1.4 mi south on U.S. 97 and make a hard right turn on Wimp Way, followed by a left after 0.3 mi onto Ice Avenue. Ice Avenue ends after 2 mi at NW 43rd Street. Turn right (north) and continue about 1 mi to a "T" intersection and turn left. Stop 6 is reached by crossing the Crooked River Ranch residential and recreational development. Drive slowly and be observant for road signs. From the "T" intersection follow Chinook Drive for 2.45 mi and turn left (west) on Groundhog Road. Then make a succession of right turns onto Perch Road (0.3 mi), Steelhead Road (0.45 mi), and Rim Road Cutoff (0.4 mi). Continue for 1.2 mi on Rim Road Cutoff to the fire station and turn left on Rim Road. After 1.25 mi, turn right on Cinder Drive and continue on a winding course for 1.6 mi to Peninsula Road. Turn left on Peninsula Road and proceed 1.1 mi to North Meadow Drive. Follow North Meadow Drive for 0.55 mi and turn right on Scout Camp Trail. Continue approximately 0.7 mi to the end of the road on public land to the starting point for the hike to Stop 6. An unmarked but prominent trail descends northwestward into the Deschutes River canyon from the vicinity of the large juniper trees adjacent to the loop at the end of Scout Camp Trail. Figure 15 shows the location of specific features to be seen at this stop.

GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 6

After leaving U.S. 97, the route along Wimp Road and Ice Avenue traverses the top of several basalt lava flows. The view southward from Ice Avenue includes Tetherow Butte, a series of low cinder and spatter cones that were the source of the extensive Agency Plains basalt described en route to Stops 1, 2, and 4. Forty-third Street skirts the edge of late Pleistocene (<700,000-year-old) basalts that were erupted near Newberry Volcano, 65 km to the south. These basalts, which have prominent pressure ridges and tumuli, entered the Deschutes River canyon to the northwest of here and flowed an additional 10 km to The Cove Palisades State Park, ending just upstream from Stop 4. Most of the route across Crooked River Ranch crosses Tetherow Butte member basalts, except for the rolling hills along Cinder Drive, which are

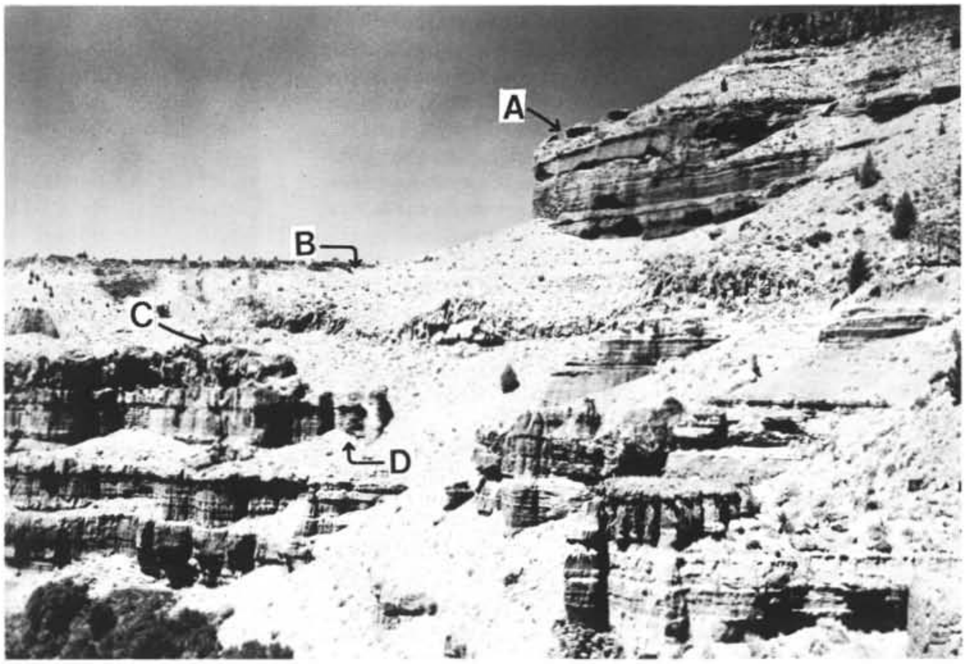


Figure 15. View to the northwest of the east wall of the Deschutes River canyon, showing locations of Stops 6a, 6b, 6c, and 6d. Light-colored cliff former extending to the right from Stop 6c is the Steelhead Falls ignimbrite member. The height of exposure from the river at lower left to the canyon rim at upper right is 200 m.

the eroded remnants of tuff cones, spatter ramparts, and small shield cones of the Steamboat Rock member of the Deschutes Formation, to be considered further at Stop 7.

STOP 6. ARC-ADJACENT ALLUVIAL PLAIN FACIES AND FACIES GEOMETRIES, DESCHUTES CANYON AT SQUAW MOUTH

The spectacular exposures of the Deschutes Formation at the confluence of Squaw Creek and the Deschutes River illustrate the complete variety of facies characteristic of the arc-adjacent alluvial plain and the importance of recognizing erosion surfaces within the stratigraphy. The stratigraphic interval exposed here is roughly correlative to that seen at Stop 4. Highlights of the section are described for four locations that are marked on Figure 15.

CAUTION: The traverse requires a steep and somewhat strenuous descent and ascent of a 120-m-high portion of the canyon wall, mostly along deer trails. Three to four hours are required to complete observations at the four designated sites.

Stop 6a

The features of interest at this location are illustrated on Figure 16. The prominent Peninsula ignimbrite member (Smith, 1986c) rests on a pumiceous debris-flow deposit and is overlain by scour-and-fill bedded pumiceous sediments.

Where entirely preserved, the ignimbrite is about 9 m thick and consists of two parts. The basal 0.9 to 1.2 m is composed of pumice lapilli and bombs up to 15 cm across, lithic fragments up to 4 cm, clasts of the underlying debris-flow deposit, and virtually no ash. Breadcrusted exteriors of many bombs and magnetic-pole orientations measured by fluxgate magnetometer indicate that this bed was emplaced hot and is best described as "fines-depleted ignimbrite" (Walker, 1983). Beds such as this occur with several Deschutes Formation ignimbrites but are rarely continuous for more than a few hundred meters. They were probably the result of turbulence generated by the roughness of the irregular landscape that the pyroclastic flow passed over. The remaining ignimbrite has a more typical ashy matrix and consists of two flow units. The basal flow unit, about 1.2 m thick, is ungraded and contains lapilli to 4 cm across and lithic fragments to 3 cm. The overlying 7-m-thick flow unit shows distinct coarse-tail

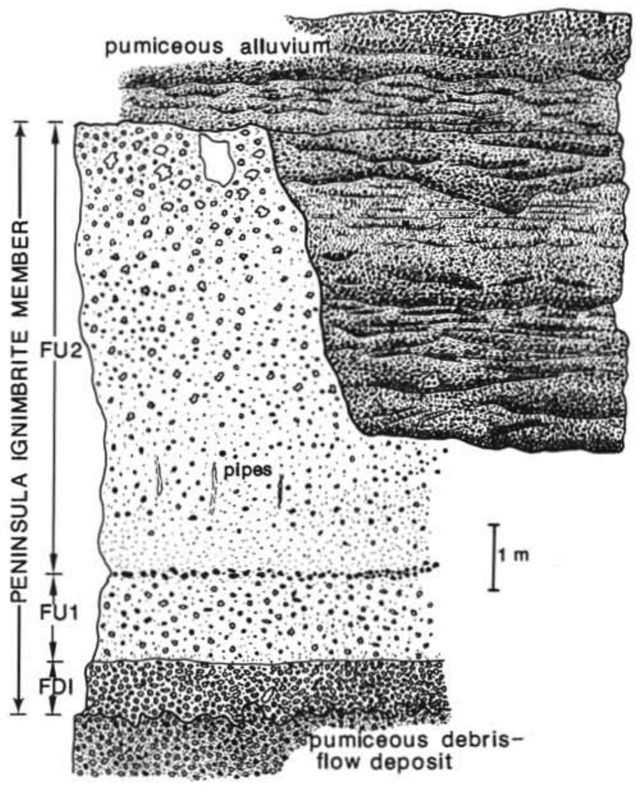


Figure 16. Schematic representation of outcrop relationships at Stop 6a. The Peninsula ignimbrite member consists of a basal fines-depleted ignimbrite (FDI) and two normal ignimbrite flow units (FU1 and FU2). The ignimbrite overlies a pumiceous debris-flow deposit along a very irregular contact and is overlain by scour-and-fill bedded sediments largely derived from the ignimbrite. Open symbols represent pumice; closed symbols represent dense lithic fragments.

normal grading of lithic fragments (from 8 cm up to 1 cm) and coarse-tail reverse grading of pumice (from 4 cm up to 40 cm); these features are common in the deposits of well-fluidized pyroclastic flows (Sparks and others, 1973). Fines-depleted pipes about 5 mm wide are locally present and represent elutriation of fine ash by rising gases following deposition. Pumice lapilli and bombs range in color from black to light-gray to white; some lapilli are banded. The white lapilli are rhyolitic in composition. Most black and light-gray lapilli are dacitic, but some of the large black bombs near the top of the ignimbrite are andesitic in composition (Smith, 1986c). Compositional heterogeneity is typical of most ignimbrites (see Hildreth, 1981, for a summary), requiring careful geochemical studies for adequate characterization of the ignimbrites for stratigraphic purposes.

About half of the approximately 100 ignimbrites known in the Deschutes Formation contain dark dacitic lapilli and ash, which accounts for the dark color of pyroclast-rich Deschutes Formation sediments that were erroneously related to basaltic provenance by some early workers. The coarse volcanic sandstones that overlie the Peninsula ignimbrite (Figure 16) are composed almost entirely of pyroclasts (lapilli and ash) derived from erosion of the unconsolidated ignimbrite. Epiclasts are also represented by clasts of tuff that were probably indurated by fumarolic alteration. These scour-and-fill bedded sediments occur in crude fining-upward sequences, 1.5 to 2.0 m thick, deposited by poorly confined, unsteady, shallow flows.

The Peninsula ignimbrite rests upon a well-indurated debris-flow deposit (Figure 16) along a very irregular contact produced by scour by the head of the pyroclastic flow. Only the upper 1-2 m of the debris-flow deposit, which totals at least 6 m in thickness, is accessible at this point. The deposit is essentially a lapilli tuff composed mostly of pumice lapilli and ash. The texture is similar to that of ignimbrites. Fluxgate magnetometer measurements of clast and matrix suggest, however, that the deposit lacks a thermal remanent magnetization. Several other observations also argue against a pyroclastic-flow origin: First, the matrix is very fine grained; very fine ash is generally elutriated from moving pyroclastic flows (compare hand samples of the debris-flow deposit and the Peninsula ignimbrite). Second, the matrix is locally vesicular, a feature caused by entrapment of air in a largely water-saturated matrix. Third, and less diagnostic, limb and trunk casts occur at the base of the deposit, and the impressions preserve bark, rather than charcoal, texture. Because most voluminous volcanic debris flows are generated by the mobilization of pyroclastic materials, they form pyroclastic deposits, and great care must be taken to distinguish them from texturally similar ignimbrites.

Stop 6b

A number of interesting features can be seen from a vantage point (Figure 15) on this spinelike ridge extending into the Deschutes Canyon. The principal features are described with respect to azimuth of view.

53°: The scale of channels in the alluvial plain sequence is dramatically illustrated by the ~15-m-high, vertical channel-wall margin preserved in the cliff-face exposure (Figure 17). Channels of this type are the typical architectural elements of the alluvial-plain sequence and can, in most cases, be correlated to paleosols developed in interchannel areas. Note that nearly all of the sedimentary facies visible on this cliff face appear to represent deposition by debris flows, hyperconcentrated flows, and other high-discharge flow processes. Fluvial gravels like those seen at Stops 2 and 3 are uncommon here and are rarely more than 1-2 m thick. Deposition of coarse flood and debris-flow transported sediment at this distance from source (~35 km) was probably in response to volcanic events. Inter-eruption periods are represented by channel incision and little to no net deposition (Smith, 1987d, in press). Because of the lack of well-developed cross-bedding or cobble

Figure 17. Steep channel margin marked by arrows within flood and debris-flow-deposited strata described at Stop 6b. Large boulder above lower arrow is about 1.7 m in diameter. Note circled figure at lower left for scale.

imbrication within the alluvial-plain facies, channel orientations are the primary source of paleocurrent data; this channel wall strikes at about N. 20-30° E.

348°: This panoramic view down the Deschutes River canyon shows typical exposures of dark-colored sediments, dark-brown to black basalt and basaltic andesite flows (some with underlying, red "baked" zones), tan and pink ignimbrites, and white pumice-fall deposits comprising the arc-adjacent alluvial-plain sequence within the Deschutes Formation. High on the west wall of the canyon are alternating light-brown and white layers below the rimrock basalt that represent the paleosol and tephra-dominated top of the alluvial-plain section, as was also seen at Stop 4b. The prominent juniper-studded benches low on the canyon wall are the younger Pleistocene intracanyon basalt flows.

233°: This direction provides a view up Squaw Creek canyon, which follows close to the margin of the rimrock basalt flow. The lava is about 10-15 m thick on the north side of the canyon but thins to a margin on the south side.

108°: High on the east wall of the Deschutes Canyon is the margin of a channel that was filled by basalt; this channel trends N. 45° E. In the middle of the slope is a cliff-forming welded ignimbrite that will be examined at Stop 6c.

Stop 6c

The Steelhead Falls ignimbrite member is an important stratigraphic marker in the southern Deschutes basin (Smith, 1986c). At this locality, the unit grades from a 3- to 5-m-thick, gray, unwelded base, to a middle 8- to 10-m-thick crudely columnar jointed welded tuff that is tan or gray but weathers orange-brown, up to a slope-forming 5-m-thick unwelded top. In the northern part of the exposure, a rather abrupt transition from the unwelded base to the welded middle zone has been accentuated by weathering to produce a pseudo-bedding plane that does not extend southward. Length-to-width ratio for pumice lapilli increases from 3-6:1 for the unwelded base to 7-14:1 for the welded middle zone and reflects the compaction of lapilli to form fiamme in the welded tuff. No systematic grading of pumice or lithics is apparent in this unit, although a fine-grained inversely graded base is locally developed and consistent with implied high basal shear stresses during emplacement. Limited analyses suggest a dacitic composition for all of the pumice in this ignimbrite (Smith, 1986c). The ignimbrite rests on as much as 1 m of pumice-fall lapillistone.

At this location, the Steelhead Falls ignimbrite rests on a thin bioturbated sand that overlies basaltic flow breccia. This is the eroded margin of the lava flow, and this stratigraphic position is occupied by sediments to the south. The ignimbrite filled a southeast-northwest-trending trough composed of inset channel fills. Lower in the section there are a number of exposed channel margins that trend N. 70-80° W.

Stop 6d

This location (Figures 15 and 18) provides additional opportunity for close scrutiny of the sedimentary facies comprising the arc-adjacent alluvial plain section. Most conspicuous here are scour-and-fill bedded units ranging in thickness from 1.5 to 10 m thick (Figure 19a). These deposits represent flashy, high-velocity, shallow flows that prohibited the production of bedforms that generate cross-bedding. Depths of scours are generally less than 25 cm and probably approximate the depths of the braided channels. The uppermost and thickest such deposit seen here is truncated by channels at the south end of the outcrop (Figure 18) but can be traced northward, roughly along depositional strike, for 1.5 km. This suggests that flows were very poorly confined and sheetlike in character. Vertically stacked scour-fill gravel lenses suggest that vertical accretion of sediment was more important than lateral accretion. The base of each sequence is often characterized by laminated fine-grained sands and silts with dispersed pumice lapilli (Figure 19b). These relatively quiet water deposits contain many leaf and stem impressions and insect burrows (Figure 19b) and tend to fill in irregularities on the underlying depositional surface. They may record overbank sedimentation during the initial stages of the depositional interval when flows were still confined to previously incised channels. Once the channels were filled, the subsequent poorly confined and strongly aggradational flows deposited the scour-and-fill bedded pebbly sands (Figure 19a) over the fine-grained sediments.

A >12-m-deep, vertical paleochannel margin truncates the thick sheetflood sequence at the south edge of the outcrop (Figure 18). A poorly indurated block of sheetflood sediment approximately 2.7 m long collapsed into this channel and can be seen at the base of the exposure. Most of the channel is filled with a generally upward fining conglomerate composed primarily of 0.5- to 5.0-cm-diameter grains with cobbles and boulders up to 1.2 m scattered throughout but largely concentrated at the base. There is virtually no component finer than 1 mm. The lower half is massive and grades into a crudely stratified upper part. Large clasts near the base are oriented with long axes parallel to the channel wall (and presumed transport direction), implying transport in a high-concentration fluid (Walker, 1975; Smith, 1986a). Low-density pumice and scoria increase in abundance upward. All of these features are consistent with deposition from a single hyperconcentrated flow. This deposit grades upward into about 2 m of bioturbated and partly oxidized sediment, which includes a remnant of an ash-fall bed and conspicuous inclined bedding. This material is interpreted as sediment that sloughed, washed, and blew into the channel over a lengthy interval of inactivity.

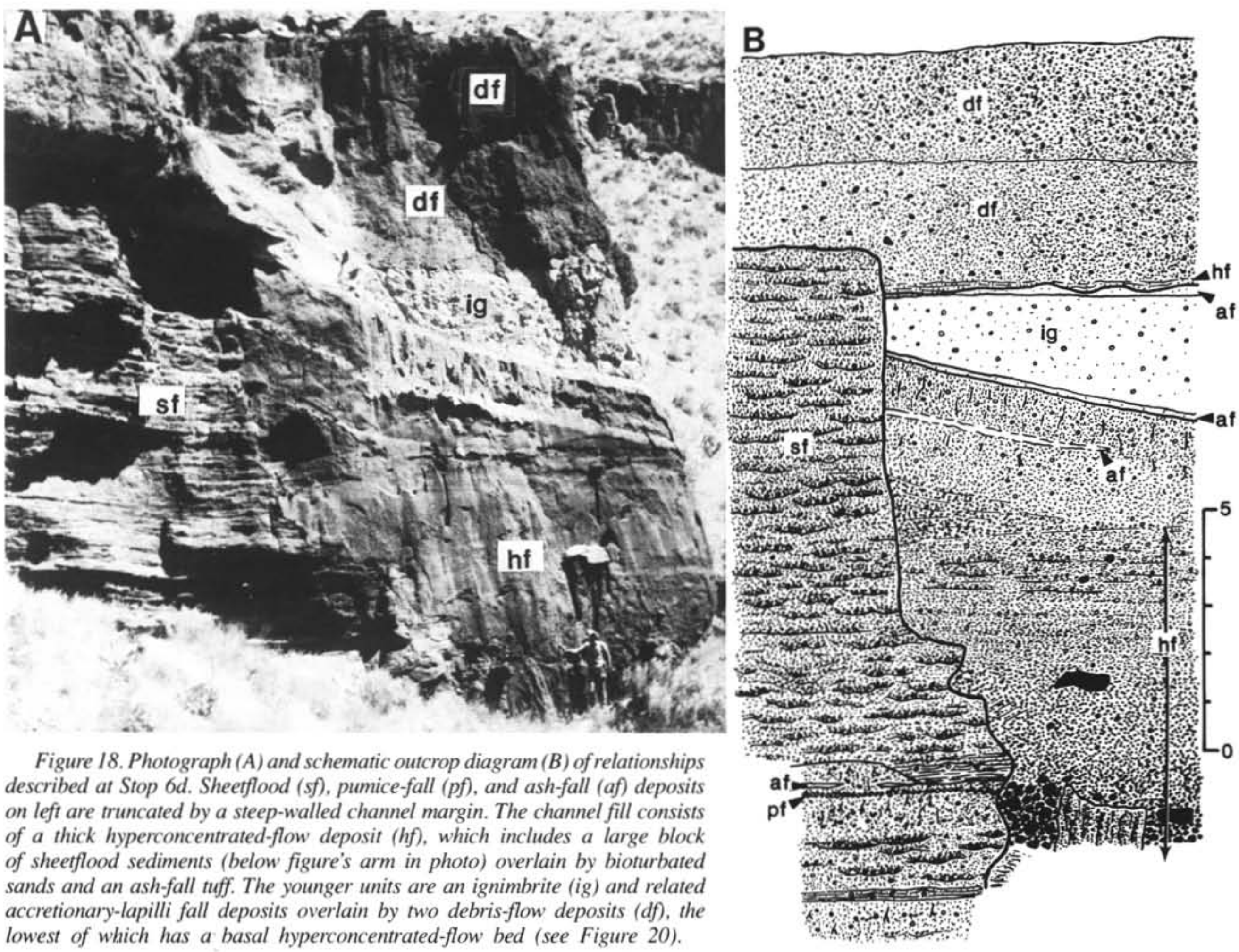


Figure 18. Photograph (A) and schematic outcrop diagram (B) of relationships described at Stop 6d. Sheetflood (sf), pumice-fall (pf), and ash-fall (af) deposits on left are truncated by a steep-walled channel margin. The channel fill consists of a thick hyperconcentrated-flow deposit (hf), which includes a large block of sheetflood sediments (below figure's arm in photo) overlain by bioturbated sands and an ash-fall tuff. The younger units are an ignimbrite (ig) and related accretionary-lapilli fall deposits overlain by two debris-flow deposits (df), the lowest of which has a basal hyperconcentrated-flow bed (see Figure 20).

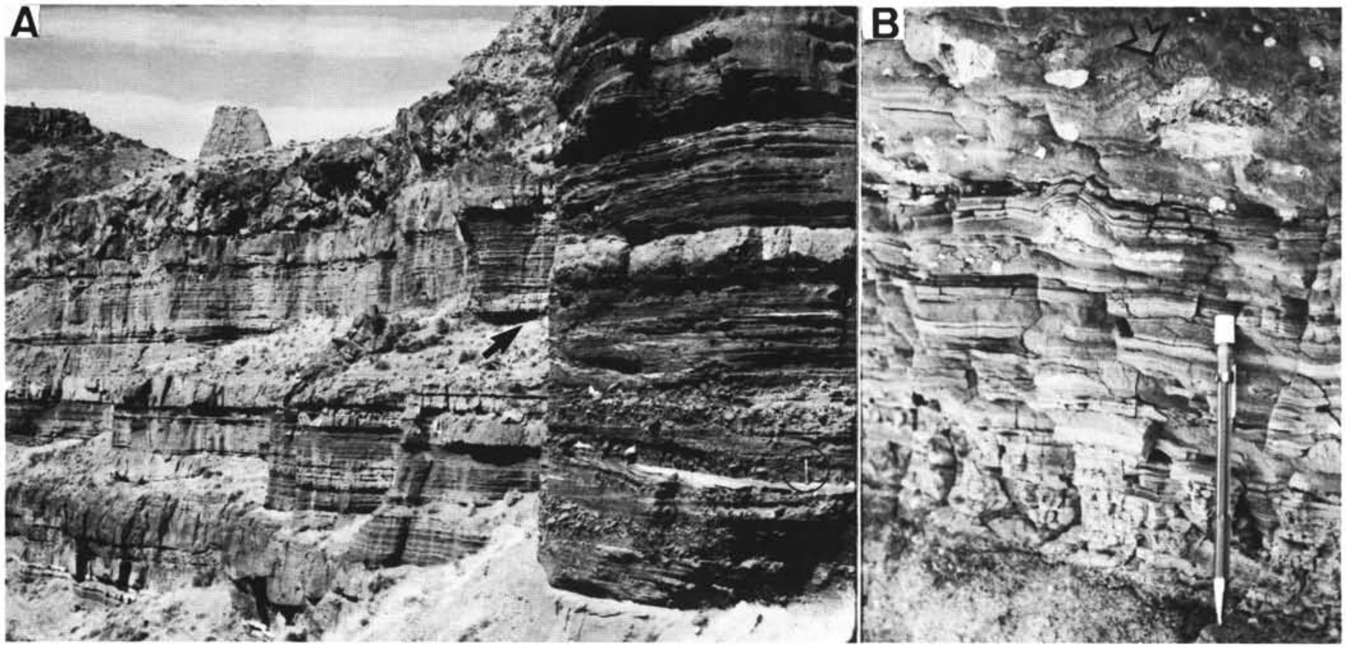


Figure 19. Sheetflood deposits typical of the arc-adjacent alluvial plain setting as exposed at Stop 6d. A. Lateral continuity of sheetflood depositional packages, showing location of Stop 6d at arrow. Foreground outcrop, with hammer for scale, illustrates typical scour-and-fill sedimentary structures and lack of cross-bedding generated by migrating bedforms. B. Coarsening-upward sands and silts at base of sheetflood sequence. Pencil tip rests on paleosol developed on lower sheetflood deposits. Note draping of laminations over pumice lapilli, above and to left of pencil, and insect burrow with meniscate fill, marked by arrow.

Figure 20. Massive debris-flow deposit containing prominent dark rhyodacitic vitrophyre clasts with basal, compositionally similar, stratified hyperconcentrated-flow deposit (between arrows).

The remaining minor paleotopography along the channel margin was filled by a fine-grained light-gray ignimbrite and associated fall deposits, which both underlie and overlie the ignimbrite (Figure 18). The falls are comprised of accretionary lapilli and fine-grained, angular ash shards. The ignimbrite also contains accretionary lapilli, along with pumice lapilli rarely exceeding 1 cm and ash. The fine-grained nature of the ignimbrite and the abundant accretionary lapilli suggest that these pyroclastics were the products of phreatomagmatic eruptions.

The youngest sediments seen at this locality are two debris-flow deposits that disconformably overlie both the ignimbrite and the sheetflood deposits adjacent to the channel fill (Figure 18). Each deposit is about 2.5 to 3.0 m thick and contains a conspicuous abundance of gray rhyodacitic vitrophyre clasts up to 3 cm long. The lower unit includes a 5- to 10-cm-thick horizontally bedded base composed of fragments of the same composition as the debris-flow deposit (Figure 20). The bedded base is inferred to represent the record of a hyperconcentrated flow that preceded the debris flow.

DIRECTIONS TO STOP 7

Retrace the route along Scout Camp Trail and North Meadow Drive to Peninsula Road. Turn right (south) and proceed 0.7 mi to West Peninsula Road. Turn right and proceed 1.15 mi to Lower Ridge Road, turn right and continue another 0.35 mi to Canyon Drive. Turn right and continue for about 0.25 mi to Stop 7; park along the right shoulder.

GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 7

West Peninsula Road skirts the flanks of an eroded basaltic tuff cone of the Steamboat Rock member of the Deschutes Formation (Figure 21) (Smith, 1986c). A thin spatter accumulation on the inner wall of the cone forms a conspicuous ledge to the east of West Peninsula Road near the junction with Lower Ridge Road. Lower Ridge Road cuts through the spatter and follows the moat between the old crater rim and a small shield cone, now capped by a water tower, within the crater. Canyon Drive descends a gully incised alongside a small lava flow that extended westward from the small shield through a breach in the crater wall.

STOP 7. PYROCLASTIC SURGE DEPOSITS

Pyroclastic base-surge deposits are the product of rapidly moving, relatively dilute, and very turbulent mixtures of ash, lapilli,

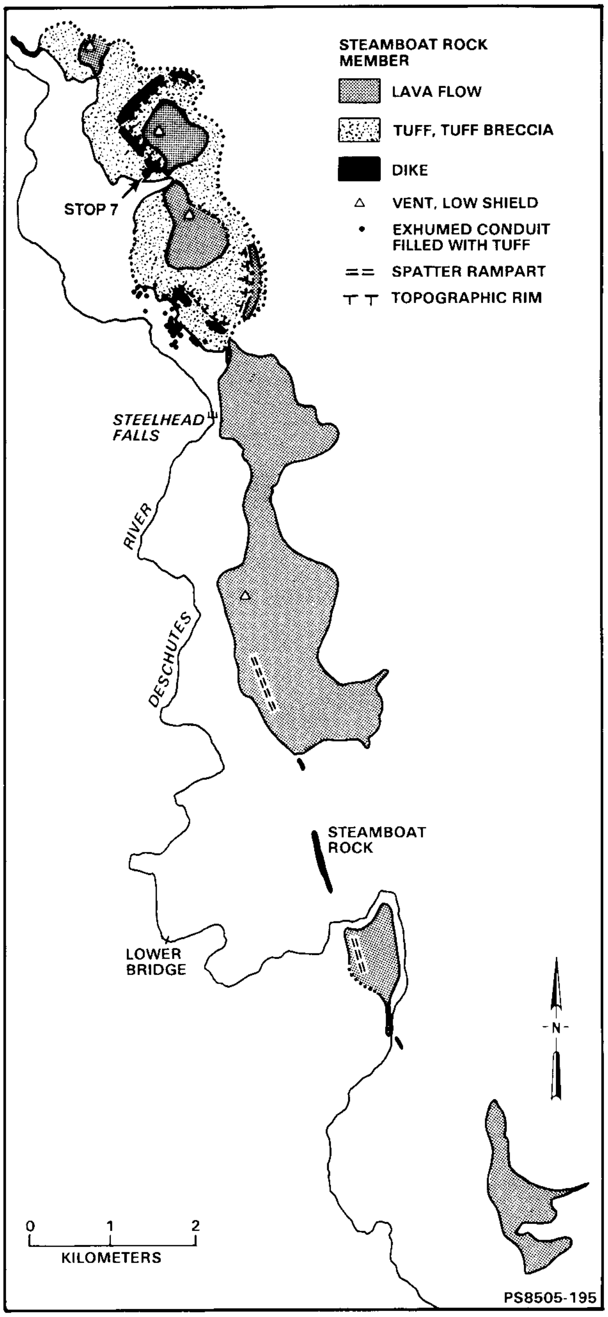


Figure 21. Map of lavas, dikes, and pyroclastic rocks of the Steamboat Rock member of the Deschutes Formation, showing location of Stop 7. Lava flows were erupted from the southern end of the fissure system, whereas phreatomagmatic eruptions along the northern fissures generated tuff rings surrounding small, late-stage shield volcanoes.

and gas (Fisher and Schmincke, 1984). Base surges move laterally from the basal part of eruptive plumes generated by phreatomagmatic eruptions and have been described in some detail by Fisher and Waters (1970). The resulting cross-bedded deposits are common in many volcanic terranes (e.g., Wohletz and Sheridan, 1979) and offer some challenge to sedimentologists, who might mistake them for fluvial or eolian facies.

The Steamboat Rock member of the Deschutes Formation includes the eruptive products related to a number of vents that formed along two en-echelon fissures that terminated near Stop 7 and extended at least 15 km to the south (Figure 21). The eruptions occurred at about 5.1 Ma (Snee, personal communication, 1985; Smith, 1986c) and represent one of several occurrences of intrabasinal volcanism during the period of High Cascade graben development. The line of the fissure vents correlates well with a steep Bouguer gravity anomaly gradient (Couch and others, 1982), suggesting that the magma rose along a deep-seated structure (Smith, 1986c). Relatively quiet Hawaiian-type eruptions along the southern part of the fissure system constructed low shield cones and spatter ramparts flanked by a thin lava flow. Magma rising along the northern part of the fissure encountered ground water, initiating phreatomagmatic explosions. Exposures of conduit structures (Figure 21) and identification of accessory-erupted clasts indicate that these explosions originated at a depth of about 250 m below the contemporary ground surface. Initial outbursts generated a basal explosion breccia, which is as much as 3 m thick but is discontinuous and no more than 0.5 m thick where exposed near the west end of exposures at this stop. Succeeding base surges produced 40 m of cross-bedded deposits at this site (Figure 22), spread from a vent centered beneath the water tower 0.5 km to the northeast.

Compared to phreatomagmatic deposits described in the literature (Fisher and Waters, 1970; Wohletz and Sheridan, 1983), those of the Steamboat Rock member represent relatively low water-to-magma-ratio explosions. Although containing a considerable volume of fine-grained, poorly vesicular, sideromelane ash, the deposits contain abundant cinder that must have formed principally by magmatic vesiculation. Other features of relatively wet eruptions, including accretionary lapilli, bomb sags, soft-sediment deformation, and oversteepened cross-beds, are absent here.

These outcrops provide an oblique section through the low crater rim, with tuffs at low elevations toward the west end of the outcrops being inclined westward away from the vent and tuffs at higher elevations to the east dipping eastward into the crater. The surge-deposited tuff and lapilli tuff are characterized by irregular pinch-and-swell structures and cross-beds that generally change westward from broad undulating trough forms to steeper trough and tabular cross-beds with preservation of both stoss- and lee-side laminae in some cases (sandwave facies of Wohletz and Sheridan, 1979) (Figure 22). These deposits also coarsen to the east. Continuous thin beds of coarse ash or cinder that drape surge bedform shapes are interpreted as fallout deposits.

The Steamboat Rock eruptions became drier with time, and basaltic tuff is overlain in many places with as much as 5 m of cinder and bombs. Outcrops of these late-stage materials are sparse at this site, but ribbon and fusiform bombs occur as float on the hillside. Fire fountains then developed within the crater to the east, veneering the inner crater wall with agglutinated spatter (capping the ridge above this locality), constructed the small shield cone beneath the water tower, and fed the lava flow that terminated on the other side of Canyon Drive. All juvenile products of the Steamboat Rock eruption are glassy, sparsely phyric transitional basalt/basaltic andesite (53.5 percent SiO_2) containing phenocrysts of augite and plagioclase. Coarser grained porphyritic basalts are prominent accessory constituents of the hydroclastic and fire-fountain deposits. They are derived from Deschutes Formation lavas about 250 m lower in the section.

Steamboat Rock member hydroclastic tuffs and lapilli tuffs may be distinguished from most similar-appearing fluvial facies by the absence of channel or scour structures and the preservation of stoss-side laminations in cross-beds (Figure 22), which are not commonly found in fluvial deposits. These hydroclastics are relatively thick near vents (up to 100 m) but do not extend more than 1 km from source. Distribution, therefore, is another helpful criterion for recognizing the primary volcanic origin of these

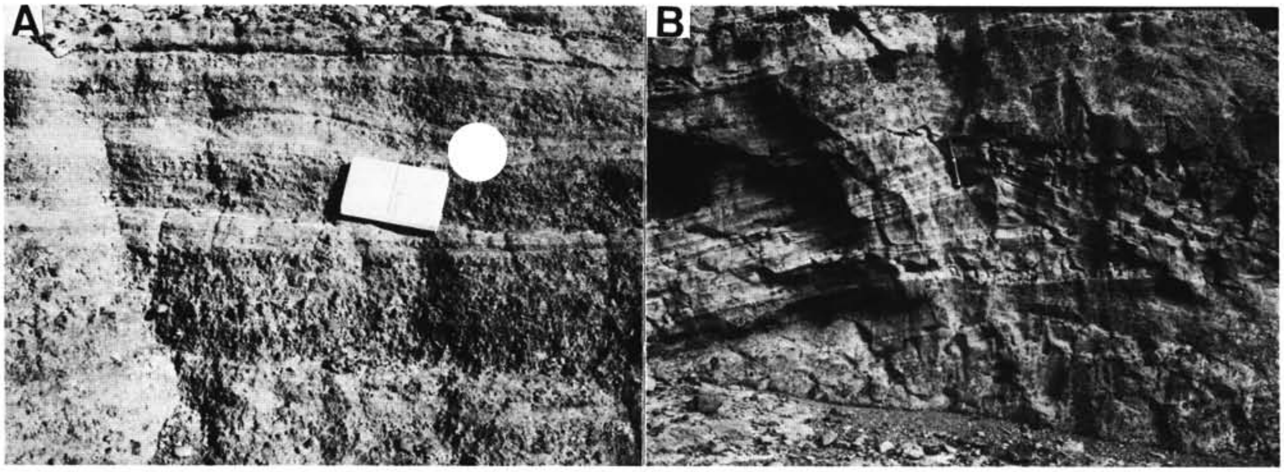


Figure 22. Depositional structures in tuffs of the Steamboat Rock member at Stop 7. A. Plane-bedded fall unit, below notebook, and cross-bedded surge deposits behind and above notebook; flow from right to left. Note sigmoidal shape of stoss-side laminations and low-angle, tabular form of lee-side laminations in preserved sand wave immediately above notebook. B. Nearly symmetrical sand-wave cross-bedding; flow from right to left.

volcaniclastic deposits. Although the sorting and abundance of coarse clasts would preclude confusing Steamboat Rock member tuffs with eolian deposits, some base surge deposits are much finer grained and can be more difficult to distinguish (Smith and Katzman, 1990).

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———1983, Hydrovolcanic explosion II. Evolution of basaltic tuff rings and tuff cones: American Journal of Science, v. 283, p. 385-413. □

DOGAMI publishes Index of Industrial Minerals Forum proceedings

Index to Proceedings of the Forum on the Geology of Industrial Minerals, First (1965) through Twenty-Fifth (1989), compiled by Robert L. Bates. DOGAMI Special Paper 24, 43 p., $6.

The Forum on the Geology of Industrial Minerals was founded in 1965 and has met every year since then. Organizations in 22 different locations in Canada and the U.S. have acted as hosts during the first 25 years. After each meeting, the papers presented at the Forum are published by the host organization. Thus earlier this year, the Oregon Department of Geology and Mineral Industries (DOGAMI) released its Special Paper 23, the proceedings of the 25th Forum held in Portland in 1989.

Because of this method of publication, it is sometimes difficult to retrieve information contained in the published proceedings. The new publication now makes that information accessible with the help of an index.

The report, which was funded in part by the Society of Economic Geologists Foundation, Inc., brings together information on all the publications of the Forum's first quarter-century. The first section consists of the titles, citations, and contents of each volume of proceedings. Then comes a subject index, followed by an author index. Each entry of these indexes is keyed to the appropriate volume of proceedings, so the reader may find the title and full citation of a desired paper by referring to the first section. At the close of the report is an address list of the agencies that have acted as Forum hosts. □

BLM appoints new managers

The U.S. Bureau of Land Management (BLM) has two new leaders in the Northwest: Robert D. Rheiner, Jr., was named associate state director for Oregon/Washington, and Michael T. Green will be the new District Manager for the agency's Burns District in Oregon.

Rheiner, a forester and veteran manager with BLM is currently the manager of BLM's Bakersfield District in California. He succeeds Paul M. Vetterick, who retired November 1, 1990. In 25 years of service with BLM, Rheiner has worked not only in California but also in Colorado, Idaho, and Washington, D.C.

Green is a 20-year veteran of BLM with a degree in wildlife management and working experience in Idaho, Alaska, and, most recently, Washington, D.C., where he worked on the budget staff of BLM's headquarters. □

MINERAL EXPLORATION ACTIVITY

MAJOR MINERAL-EXPLORATION ACTIVITY

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services, Inc.	Tps. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	Jessie Page Chevron Resources Company	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Company	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
May 1989	Hope Butte Chevron Resources Company	T. 17 S. R. 43 E. Malheur County	Gold	Expl, com
September 1989	East Ridge Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	App
June 1990	Racey Billiton Minerals USA	T. 13 S. R. 41 E. Malheur County	Gold	Expl
June 1990	Grouse Mountain Bond Gold Exploration, Inc.	T. 23 S. Rs. 1, 2 E. Lane County	Gold	Expl
June 1990	Freeze Western Mining Corporation	T. 23 S. R. 42 E. Malheur County	Gold	Expl
August 1990	Lava Project Battle Mountain Exploration	T. 29 S. R. 45 E. Malheur County	Gold	Expl
September 1990	Bourne Simplot Resources, Inc.	T. 8 S. R. 37 E. Baker County	Gold	App
September 1990	Baboon Creek Chemstar Lime, Inc.	T. 19 S. R. 38 E. Baker County	Lime-stone	App
September 1990	Prairie Diggings Western Gold Exploration and Mining Co.	T. 13 S. R. 32 E. Grant County	Gold	App
September 1990	Pine Creek Battle Mountain Exploration	T. 20 S. R. 34 E. Harney County	Gold	Expl
September 1990	Calavera NERCO Exploration Company	T. 21 S. R. 45 E. Malheur County	Gold	Expl
September 1990	Cow Valley Butte Cambiex USA, Inc.	T. 14 S. R. 40 E. Malheur County	Gold	Expl
September 1990	Mahogany Project Chevron Resources Company	T. 26 S. R. 46 E. Malheur County	Gold	App
October 1990	Katey Claims Asarco, Inc.	Tps. 24-25 S. Rs. 44-46 E. Malheur County	Gold	Expl
October 1990	Snake Flat Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	App
October 1990	Stockade Mountain BHP-Utah International	T. 26 S. Rs. 38, 39 E. Malheur County	Gold	Expl
October 1990	Goldfinger Site Noranda Exploration	T. 25 S. R. 45 E. Malheur County	Gold	Expl
October 1990	Buck Gulch Teague Mineral Products	T. 23 S. R. 46 E. Malheur County	Ben-tonite	Expl
November 1990	Sand Hollow Noranda Exploration	T. 24 S. R. 43 E. Malheur County	Gold	Expl
November 1990	South Star Claims Carlin Gold Company, Inc.	T. 25 S. R. 39 E. Malheur County	Gold, silver	App
November 1990	Stockade Project Phelps Dodge Mining Company	Tps. 25, 26 S. R. 38 E. Malheur County	Gold	App
November 1990	Bornite Project Plexus Resources Corporation	T. 8 S. R. 3 E. Marion County	Copper	App
November 1990	Martha Property Cambiex USA, Inc.	T. 33 S. R. 5 W. Josephine County	Gold	App

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued.

Status changes

During October and November, ten new applications were received. Bond Gold completed exploration and reclamation of its Noonday Ridge project, and the file has been closed. Reclamation on numerous sites was totally or partially completed prior to the onset of winter weather. Permits will not be closed, and some bond money will be held until disturbed areas are successfully revegetated.

Questions or comments about exploration activities in Oregon should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office, 1534 SE Queen Avenue, Albany OR 97321, telephone (503) 967-2039. □

MLR office adds staff member

Douglas A. Galipeau has joined the Mined Land Reclamation Program (MLR) of the Oregon Department of Geology and Mineral Industries in Albany.

A mining engineer by his professional training, Galipeau comes to MLR from a position as cavern engineer for an underground salt mine project of Boeing Petroleum Services in Louisiana. During the past 15 years, he also has had working experience in surface coal mining in Wyoming and in well drilling, both for oil exploration and water wells.

As Environmental Specialist, Galipeau is a welcome addition to the MLR staff that administers the continually growing program of regulating mining exploration and development in Oregon. □

Significant Oregon earthquakes in 1990

Since 1970, the University of Washington has operated a seismic network in Oregon capable of recording relatively small earthquakes. In 1990, the network was expanded with four new stations near Corvallis, Eugene, and Roseburg. In addition, Oregon State University began operating a high-gain, broadband seismic station in Corvallis in 1990. Also in 1990, the University of Oregon received funding to install a network of six broadband instruments throughout the state. These improvements in instrumentation promise to teach us a great deal about Oregon seismicity in the years to come.

As a service to the readers of *Oregon Geology*, the Oregon Department of Geology and Mineral Industries (DOGAMI) will, in the future, publish reports of significant earthquakes in Oregon as they occur. A complete catalog of Oregon earthquakes and quarterly updates published by the University of Washington are available in the DOGAMI library.

Seismic activity in Oregon is low in comparison to neighboring states, but three significant earthquakes or groups of earthquakes were recorded in Western Oregon this year.

HEMBRE RIDGE EARTHQUAKE

At 9:56 p.m. on April 5, 1990, a magnitude (mc) 3.2 earthquake occurred about 22 km east of Tillamook. The earthquake was located at a depth of 43.5 km beneath Hembre Ridge in the Coast Range. The focal mechanisms calculated for this event are poorly constrained and preliminary. One solution suggests SE thrust motion on a fault which strikes 040° (NE) and dips 8° NW. The other solution suggests reverse motion on a fault that strikes 040° (NE) and dips 82° SE. This event was felt by several people in the Tillamook area and was reported to local emergency management agencies.

WOODBURN EARTHQUAKEES

A swarm of earthquakes occurred beneath Woodburn, Oregon, between August 14 and August 23, 1990. The smallest event recorded had a magnitude (mc) of 1.4, the largest had a magnitude (mc) of 2.5. The earthquakes occurred at a depth of 29 km and were not reported as felt. Nabelek and others (1990) report that seismic waveforms recorded by the Oregon State University broadband seismic station were remarkably similar, suggesting identical locations and mechanisms. The authors estimate a focal mechanism of right-lateral strike-slip motion with a small thrust component on a fault plane striking 340° (NNW) and dipping steeply east. They suggest that the earthquake swarm was located near, and was possibly associated with, the Mount Angel Fault that cuts Columbia River basalt and overlying alluvial deposits.

MOUNT HOOD EARTHQUAKE

An earthquake was felt by residents of Government Camp and Timberline Lodge at Mount Hood on October 18, 1990. The epicenter was located at Timberline Lodge, and the earthquake occurred at a depth of 6 km with a magnitude (mc) of 3.5. The main event was accompanied by two small foreshocks and several dozen aftershocks. The focal mechanism was estimated as either left-lateral slip on a plane striking 030° (NNE) and dipping 48° NW or right-lateral slip on a plane striking 330° (NNW) and dipping 60° NE. Both focal mechanisms have a component of normal dip slip.

This earthquake was very similar to earlier events at Mount Hood in 1989, 1982, and 1974.

ACKNOWLEDGMENTS

Information for this report was cheerfully provided by Craig Weaver and Tom Yelin of the U.S. Geological Survey office at the University of Washington, Steve Malone and Chris Jonientz-Trisler of the University of Washington Geophysics Program, John Nabelek of the Oregon State University College of Oceanography, and Gene Humphreys of the University of Oregon Department of Geosciences.

REFERENCE CITED

Nabelek, J., Werner, K., Yeats, R.S., and Malone, S., 1990, The August 1990 Woodburn, Oregon, earthquake sequence: Constraints from broadband regional recording and geological implications [abs.]: EOS, v. 71, no. 41, p. 1145. □

AEG to host international symposium

The 15th International Geochemical Exploration Symposium of the Association of Exploration Geochemists (AEG) will be held April 29 to May 1, 1991, at Bally's Casino Resort in Reno, Nevada.

The Symposium's technical sessions will discuss geochemistry of gold and platinum deposits, integrated geophysical and geochemical exploration, and new analytical techniques. Poster sessions will be held concurrently. Fourteen field trips, three short courses, and two workshops will be divided between pre- and post-meeting times, and 150 industry vendors, consultants, and professional organizations will present displays and information stands.

For more information regarding program, registration, and accommodations, phone Mario Desilets at (702) 784-6691 or Erik Rorem at (702) 359-9330 or write to: 15th International Geochemical Exploration Symposium, P.O. Box 9126, Reno, NV 89507. □

NWMA elects officers and trustees

The Northwest Mining Association (NWMA) elected new officers and trustees for the year 1991 at its 96th annual convention in Spokane last December.

The following officers were elected: President, David A. Holmes of Behre, Dolbear and Company, Inc.; First Vice President, Marshall A. Koval of Golder Associates; Second Vice President, John M. Willson of Pegasus Gold; Vice President, Karl W. Mote of the Northwest Mining Association; Secretary, John L. Neff of Nayes, Phillabaum and Harlow; and Treasurer, David M. Menard.

As trustees, the following were elected: Brian R. Hanson of Holland and Hart; Rod Higgins of Coeur d'Alene Mines Corporation; Keith R. Hulley of USMX, Inc.; John D. Marrington of Dynatec Mining Corporation; Leigh A. Readdy of Geological and Exploration Associates; Michael B. Richings of Atlas Precious Metals, Inc.; Linda E. Thorstad of Interaction Resources, Ltd.; and Christopher L. Widrig of Dupont Company.

—*NWMA news release*

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Beverly F. Vogt, Publications Manager

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