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THIS MONTH:
SIMTUSTUS FORMATION:
A NEWLY DEFINED GEOLOGIC UNIT

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

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 DOGAMI.

COVER PHOTO

Northward view across Lake Simtustus on the Deschutes River. Article beginning on next page discusses the Simtustus Formation, shown on this photo as unit *Ts* interstratified with and overlying Columbia River basalt flows (*Tcr*). Dashed line denotes approximate position of unconformity between the Simtustus (*Ts*) and Deschutes (*Td*) Formations. Ledge-forming basalt above the unconformity is the Pelton basalt member. Mutton Mountains are on the skyline.

Notice of change

During the next one month or two the mailing of *Oregon Geology* will undergo some significant — and we hope beneficial — changes. The mailing itself will be taken over by a mailing service outside the Department, and the maintenance of the mailing list will be handled with the help of a computer.

Please bear with us, if some problems occur during the transition. Let us know soon if you do not receive your magazine or if your address should not be quite correct. That address, by the way, will include a code number whose last four digits will tell you the expiration month and year of your subscription. Please take note of it as a timely reminder to renew!

— *The editors*

DOGAMI releases open-file reports

Geothermal gradient data for 1982-1984: The Oregon Department of Geology and Mineral Industries (DOGAMI) has released geothermal gradient data collected from 1982 through 1984 and placed them on open file as Open-File Report O-86-2.

The 107-page report contains all temperature-gradient measurements taken by the staff of DOGAMI and the Oregon Department of Water Resources in 42 drill holes throughout the state. For each of the drill holes, which are arranged by township from north to south, the computer-produced report contains data tables and temperature-depth plots as graphic summaries.

The report was compiled by D.D. Blackwell, Southern Methodist University, G.L. Black and G.R. Priest, DOGAMI, and funded by a grant from the U.S. Department of Energy (price, $5).

Inventory of data on coastal black sands: A comprehensive inventory of existing data on coastal heavy-mineral-bearing "black sands," a potential source of such strategic metals as chromium and titanium, has also been released by DOGAMI. The new release, DOGAMI Open-File Report O-86-10, is entitled *Inventory of Heavy Minerals and Metals — Southern Washington, Oregon, and Northern California Continental Shelf and Coastal Region* and contains data summaries of some 93 studies.

The new publication is part of the efforts by State and Federal agencies investigating the newly expanded areas under United States jurisdiction proclaimed in 1983 as Exclusive Economic Zone (EEZ). The report was produced by the Oregon State University College of Oceanography with funding from the U.S. Minerals Management Service. The authors are marine geologists LaVerne D. Kulm, Curt D. Peterson, and Margaret C. Stribling.

The 111-page report is divided into three major sections. The text outlines a long-range plan for exploration and research of heavy-mineral-bearing sands. A graphic section includes a series of 38 maps representing all the types of data collected between 41° and 47° N. latitude. Finally, the report contains a summary of the data generated by each of the 93 studies. Each summary lists the source of the information, locational and topical information, morphological information, methods of data collection, and the data acquired in the study (price, $8).

Both reports are available for sale from the Portland office of the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. Orders under $50 require prepayment.□

Simtustus Formation: Paleogeographic and stratigraphic significance of a newly defined Miocene unit in the Deschutes basin, central Oregon

by *Gary A. Smith, Research Fellow, Northwest College and University Association for Science, Tri-Cities University Center, Richland, WA 99352*

ABSTRACT

Volcanogenic sandstones, mudstones, and tuffs of middle Miocene age in the northern Deschutes basin are conformable upon and intercalated with lava flows correlated to the Grande Ronde Basalt of the Columbia River Basalt Group. Although previously mapped as Deschutes Formation (or equivalent), the middle Miocene sediments are lithologically distinct from typical Deschutes Formation rocks, and the two units are separated by an angular and erosional unconformity representing a hiatus of 5 to 7 million years (m.y.). The name Deschutes Formation is retained for the younger sequence, and the name Simtustus Formation is herein proposed for the older rocks. Fluvial channel and flood-plain aggradation during Simtustus time was probably induced by drainage disruption and base-level rise associated with emplacement of the voluminous Columbia River flood basalts. Western Cascade volcanoes were the provenance for most Simtustus Formation sandstones, but these sandstones are dominated by pyroclastic debris which is subordinate to other lithologies in the contemporary Western Cascades volcanic sequences. This discrepancy reflects preferential erosion of unconsolidated pyroclastic debris from proximal volcanic centers and its subsequent enrichment, relative to epiclastic material eroded from lava flows, among sediment deposited in distal sedimentary basins.

INTRODUCTION

The Tertiary stratigraphy of central and eastern Oregon is characterized by sequences of volcanic and nonmarine, largely volcanogenic, sedimentary rocks (Walker, 1977). Although many of the volcanic rocks have been the subject of petrologic and stratigraphic study, little effort has been made to evaluate the stratigraphy and sedimentology of the sedimentary units or their paleogeographic and tectonic significance. Many of the sedimentary units host fossil floras and faunas that have been the subject of paleontological scrutiny for over a century, but rarely were these studies coupled with stratigraphic investigations. As a result, the contact relationships of paleontologically dated units with adjacent rocks are generally unknown, the lithologies are often undescribed, and stratigraphic nomenclature is either lacking altogether or ambiguously defined from reconnaissance mapping.

This paper describes a newly recognized Miocene unit, herein named the Simtustus Formation, in the Deschutes basin of central Oregon, and discusses its depositional environment, relations to previously defined units, and significance to regional stratigraphy. Of particular importance is the interstratification of the Simtustus Formation with basalts correlative to the Columbia River Basalt Group. A recognized stratigraphy exists for sedimentary rocks interbedded with the Miocene flood basalts in most of central and eastern Washington (Swanson and others, 1979), but a comparable understanding of interbed stratigraphy is lacking for Oregon.

The Deschutes basin is that area of central Oregon south of the Mutton Mountains, north of the High Lava Plains, east of the High Cascade Range, and west of the Ochoco Mountain foothills

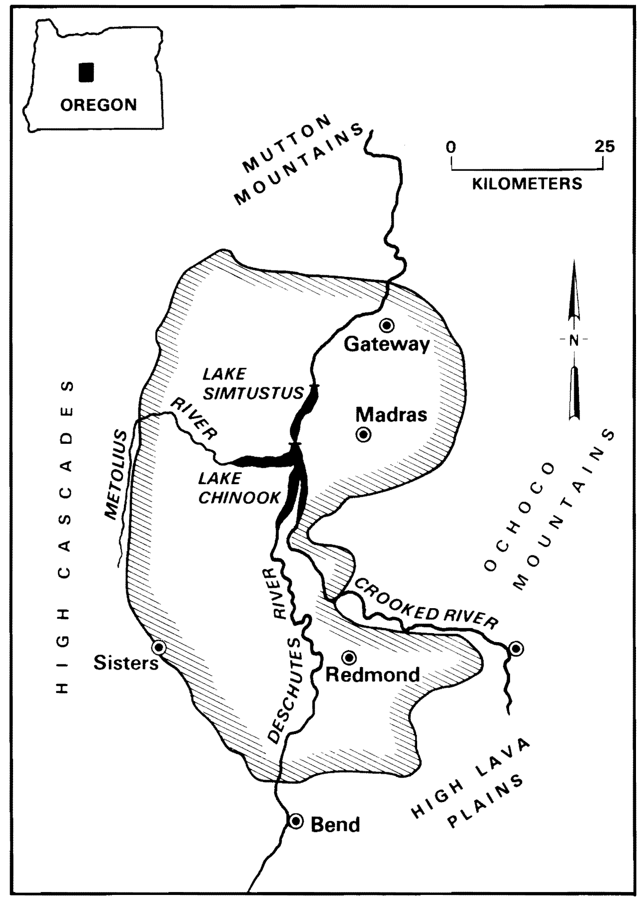

Figure 1. Location map of central Oregon showing limits of the Deschutes basin (shaded area).

(Figure 1). This region, currently integrated into the Columbia River drainage system via the north-flowing Deschutes River, has been the site of episodic emplacement of volcanic and volcanogenic sedimentary rocks since at least middle Eocene time. Surface exposure is dominated by rocks of Neogene age derived both from the Cascade Range and volcanic sources within and east of the basin.

Exposures of the middle to upper Eocene Clarno Formation and Oligocene to lower Miocene John Day Formation are largely restricted to structurally high areas north and east of the Deschutes basin. Large rhyolite domes and smaller knobs of dacite assigned to the John Day Formation (Smith, 1986) also occur as inliers within the basin, surrounded and partially buried by younger rocks.

The John Day Formation is unconformably overlain by middle Miocene basalt flows of Prineville chemical type (Uppuluri, 1974), which are stratigraphically equivalent to the Grande Ronde Basalt of the Columbia River Basalt Group (Smith, 1986). The Grande Ronde Basalt is the oldest of three formations in the Yakima Basalt Subgroup that are widespread in central and eastern Washington and northern Oregon and that were erupted from fissure vents in southeastern Washington and northeastern Oregon. The Prineville chemical-type flows in the Deschutes basin were probably erupted from now-buried vents located south of Powell Buttes and then flowed northward through the basin and were intercalated with Grande Ronde Basalt flows north of the Mutton Mountains. Correlation of Prineville chemical-type flows in the Deschutes basin with flows of similar composition within the Grande Ronde Basalt farther north (Swanson and others, 1979) warrants inclusion of the Deschutes basin basalts within the Grande Ronde Basalt (Smith, 1986).

Within the basin, middle Miocene basalts are overlain by and intercalated with volcanic and volcaniclastic rocks of largely Cascade provenance that comprise the Simtustus and Deschutes Formations. Pleistocene basalt flows and pyroclastic deposits locally overlie the Neogene section and partly fill 50- to 250-m-deep canyons incised during late Pliocene and early Pleistocene time by the Deschutes River and its tributaries. The base of the exposed section is progressively older to the north as a result of northward increase in the depth of incision and southerly dips on the south flank of the Mutton Mountains.

PREVIOUS WORK

Volcanic and sedimentary rocks of Miocene to early Pliocene age overlying the Columbia River Basalt Group in the Deschutes basin have been referred to by three names. These rocks have been named (1) Deschutes sands (Russell, 1905) or Deschutes Formation (Stearns, 1930; Moore, 1937; Stensland, 1970; Taylor, 1973, 1980; Peterson and others, 1976; Jay, 1982; Hayman, 1983; Farooqui and others, 1981a,b; Smith and Priest, 1983; Smith, 1986); (2) Madras Formation (Hodge, 1928,1940; Williams, 1957; Hewitt, 1970; Robinson and Price, 1963; Robinson and Stensland, 1979; Robinson and others, 1984); and (3) Dalles Formation (Hodge, 1942; Waters, 1968a; Robinson, 1975; Robison and Laenen, 1976). Farooqui and others (1981a,b) proposed retaining usage of Deschutes Formation because the name Deschutes has historic priority and placed the formation, along with other units in north-central Oregon that had been previously mapped as Dalles Formation, into their Dalles Group.

A type section was never defined by previous workers, but most have referred to exposures in the canyons of the Deschutes and Crooked Rivers upstream from Round Butte Dam as typical of the unit. In this region, the Deschutes Formation consists of dark-gray to black, pebbly, coarse-grained sandstones, cobble to boulder conglomerates, and minor tuffaceous mudstones and diatomites, interbedded with pumice lapillistones and more than a hundred ignimbrites and lava flows. Exposures illustrating this lithologic assemblage near Round Butte Dam have been suggested as a type section (Smith, 1986).

Studies of fossil leaves (Chaney, 1938; Ashwill, 1983) and fish bones (Cavender and Miller, 1972) indicate a late Miocene to early Pliocene age for the Deschutes Formation. Isotopic dates by $^{40}Ar/^{39}Ar$ methods indicate a range in age from about 7.6 million years (m.y.) (Smith and Snee, 1984) for the Pelton basalt member, the lowest basalt flow in the Deschutes Formation, to about 4.0 m.y. (L.W. Snee, personal communication, 1985) for basalts at the top of the formation. However, most of the Deschutes Formation was deposited prior to 5.6 million years before the present (m.y. B.P.)(Smith, 1986). Vertebrate fossils indicative of a Hemingfordian-Barstovian age (12.0 to 21.0 m.y.; all land mammal ages from Berggren and others, 1985) were described by Downs (1956) from localities near Gateway, which are stratigraphically between rocks of the Columbia River Basalt Group and rocks hosting Hemphillian-age (5.0 to 9.0 m.y.) fish fossils (Cavender and Miller, 1972) below the Pelton basalt member. The rocks hosting the Hemingfordian-Barstovian-age fossils were subsequently mapped as Dalles Formation (Waters, 1968a; Robinson, 1975) or lower Deschutes Formation (Hayman, 1983).

Jay (1982) and Hayman (1983) were the first workers to make a detailed evaluation of the stratigraphy of the Columbia River Basalt Group and overlying rocks in the Round Butte Dam to Gateway area. They designated all rocks overlying the Columbia River Basalt Group as Deschutes Formation, including those hosting Downs' (1956) fossils, thus extending the age of the base of the Deschutes Formation to middle Miocene. These two workers also recognized that the Columbia River Basalt Group is represented by two flows separated by a sedimentary interbed. Jay (1982) assigned the interbed to the Deschutes Formation, but Hayman (1983) mapped the interbed as a separate, unnamed unit.

Smith and Hayman (1983) gave a preliminary report of evidence for an unconformity separating Hemphillian fossil localities beneath the Pelton basalt member and Downs' (1956) Hemingfordian-Barstovian fossil localities. They proposed retaining Deschutes Formation for the upper unit and informally used Lake Simtustus formation for rocks below the unconformity and interbedded with the Columbia River Basalt Group. The name was shortened to Simtustus formation by Smith and Priest (1983) and Smith and Snee (1984) and has been reserved by the U.S. Geological Survey Geologic Names Committee (V. Langenheim, personal communication, 1984).

DEFINITION OF SIMTUSTUS FORMATION

Volcaniclastic rocks conformable upon, and interbedded with, the Columbia River Basalt Group in the Deschutes basin and lithologically distinct from other rocks in the basin are herein named the Simtustus Formation. Probable extension of the unit outside of this area is left for future workers. The name is derived from Lake Simtustus, the reservoir impounded behind Pelton Dam on the Deschutes River west of Madras (cover photo). The type section is defined and described from a composite of three exposures on the eastern canyon wall near the reservoir, and two reference sections are designated near Gateway (Figure 2; Smith, 1986). These sections illustrate most of the lithologic diversity of the formation but do not include an areally restricted rhyodacitic ignimbrite (Hayman, 1983; Smith and Hayman, in preparation) exposed on a hill 1.5 km southeast of Gateway. The general distribution of the Simtustus Formation is shown in Figure 3. However, the extent of the formation in the steep canyon walls is exaggerated for representation at this scale, and the reader is directed to other maps (Smith, 1986; Smith, in preparation,a,b; Smith and Hayman, in preparation) for more accurate portrayal.

As thus defined, the Simtustus Formation is 1 to 65 m thick and composed, in decreasing order of abundance, of tan, massive and laminated tuffaceous mudstone to fine-grained sandstone; light-gray to tan, cross-bedded medium- to very coarse-grained tuffaceous sandstone; small-pebble volcanic conglomerate; tuff; debris-flow breccia; and rhyodacitic ignimbrite. The name Deschutes Formation is retained for the coarse-grained volcanogenic sediments and interbedded lava flows and ignimbrites of variable composition that characterize the exposures first described by Russell (1905) and Stearns (1930) and that unconformably overlie the Simtustus Formation. These lithologies, which are distinct from the Simtustus Formation, have been considered in further detail by Stensland (1970), Hewitt (1970), Hales (1975), Jay (1982), Hayman (1983), Conrey (1985), Yogodzinski (1986), and Smith (1986). This definition represents a revision in the usage of Farooqui and others (1981a),

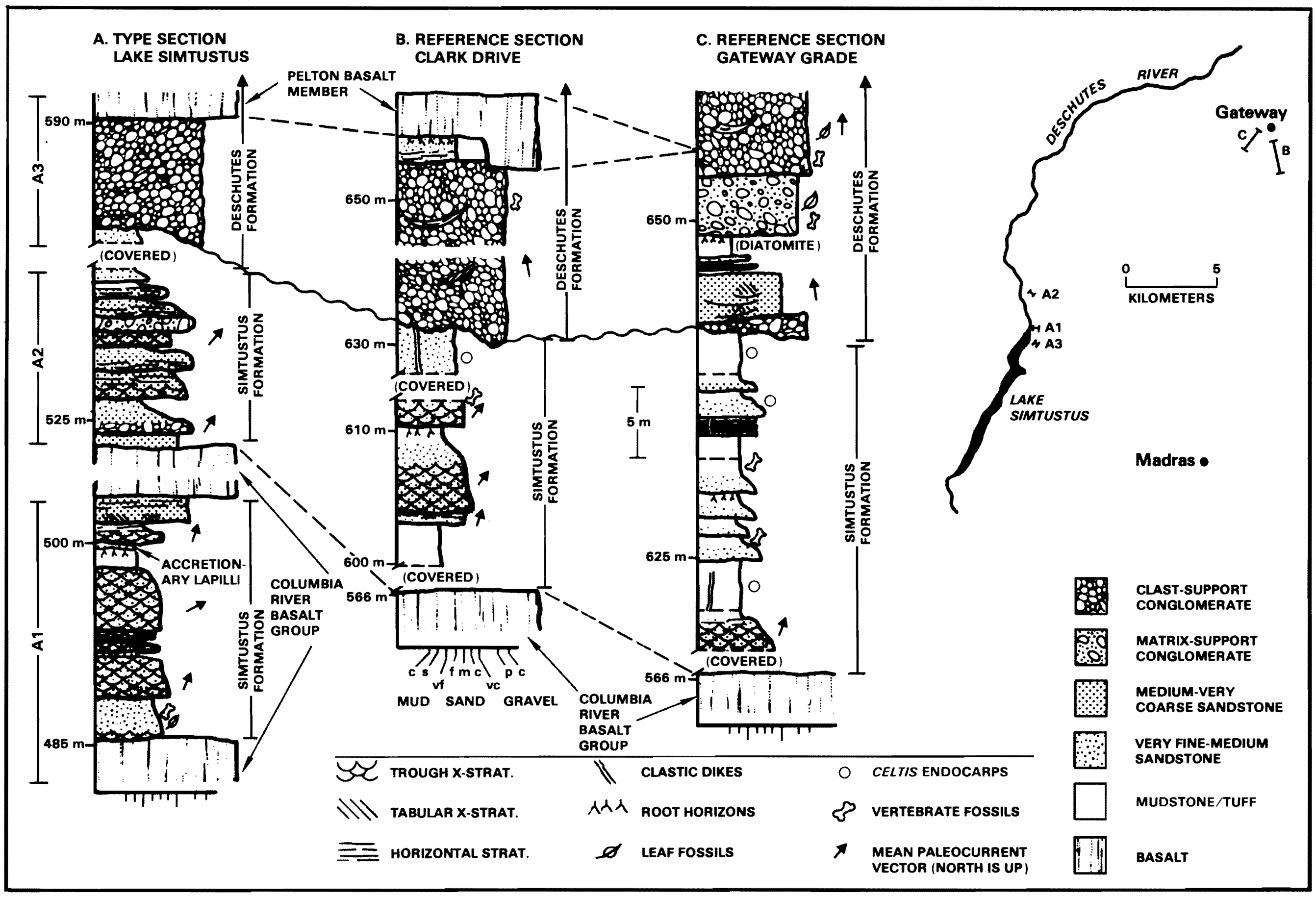

Figure 2. Graphic sections of the Simtustus Formation. Locations of all three sections shown on map in upper right corner of figure. Section A is a composite section of A1, A2, and A3.

which placed all Neogene rocks overlying the Columbia River Basalt Group in the Deschutes Formation including those now assigned to the Simtustus Formation.

Because of lithologic similarity between that part of the Simtustus Formation interbedded with the basalt and the part overlying the basalt, a single stratigraphic name is proposed. This designation follows the precedent of Swanson and others (1979), farther north on the Columbia Plateau, to restrict the Columbia River Basalt Group only to basalt and to assign sedimentary interbeds to the immediately overlying sedimentary formation of similar lithology. This approach is preferable to schemes that define formational boundaries in lithologically indistinct sedimentary units on the basis of position in the basalt sequence, because at the plateau margin, definitive basalt flows may not occur as markers (Schmincke, 1964; Swanson and others, 1979). To avoid ambiguous correlations of sedimentary units between sections with dissimilar basalt stratigraphy, member status in the Simtustus Formation is not designated for the prominent interbed in the basalts in the Deschutes basin, which hereafter is referred to informally as the lower Simtustus Formation for convenience in this paper.

Field relationships indicate that the Simtustus Formation is conformable with the Columbia River Basalt Group. In the Deschutes basin, no Simtustus Formation occurs below the Columbia River basalt that lies on the John Day Formation with up to 200 m of erosional relief and up to 10° of angular discordance (Smith, 1986). Lower Simtustus Formation sedimentation was probably initiated soon after the emplacement of the first basalt flow, because no paleosol occurs on the basalt. The second flow was emplaced during Simtustus deposition, because there is no evidence of disconformity. Locally, the second flow is invasive into lower Simtustus siltstone. The invasive relationship is recognized by the occurrence along the top of the flow of crude pillows, chilled rinds, and intermixed baked siltstone.

The Deschutes Formation overlies the Simtustus Formation with angular and erosional unconformity. In the Gateway area, the Simtustus Formation dips 5° to the southwest, as does the Columbia River Basalt Group (Hayman, 1983), while the Deschutes Formation dips less than 1° southwestward. East of Gateway, there is at least 30 m of relief on the contact between the two formations (Figure 2). West of the Deschutes River and along the eastern margin of the basin, the Deschutes Formation rests directly on the John Day Formation or Columbia River Basalt Group, indicating that either the Simtustus Formation was never deposited or that it was removed by erosion before Deschutes Formation deposition commenced. Reverse faults near the east abutment of Pelton Dam offset the Columbia River Basalt Group and the upper and lower Simtustus Formation by the same amount but do not affect the Deschutes Formation (Figure 3).

The age of the Simtustus Formation is inferred from isotopic dates and paleontological studies. The lowest Prineville chemical-type basalt flow at Pelton Dam has been dated by $^{40}Ar/^{39}Ar$ method at 15.7±0.1 m.y. B.P. (L.W. Snee, personal communication, 1985). This date is consistent with correlation of the flows at Pelton Dam to similar Prineville chemical-type basalts intercalated with low-MgO Grande Ronde Basalt north

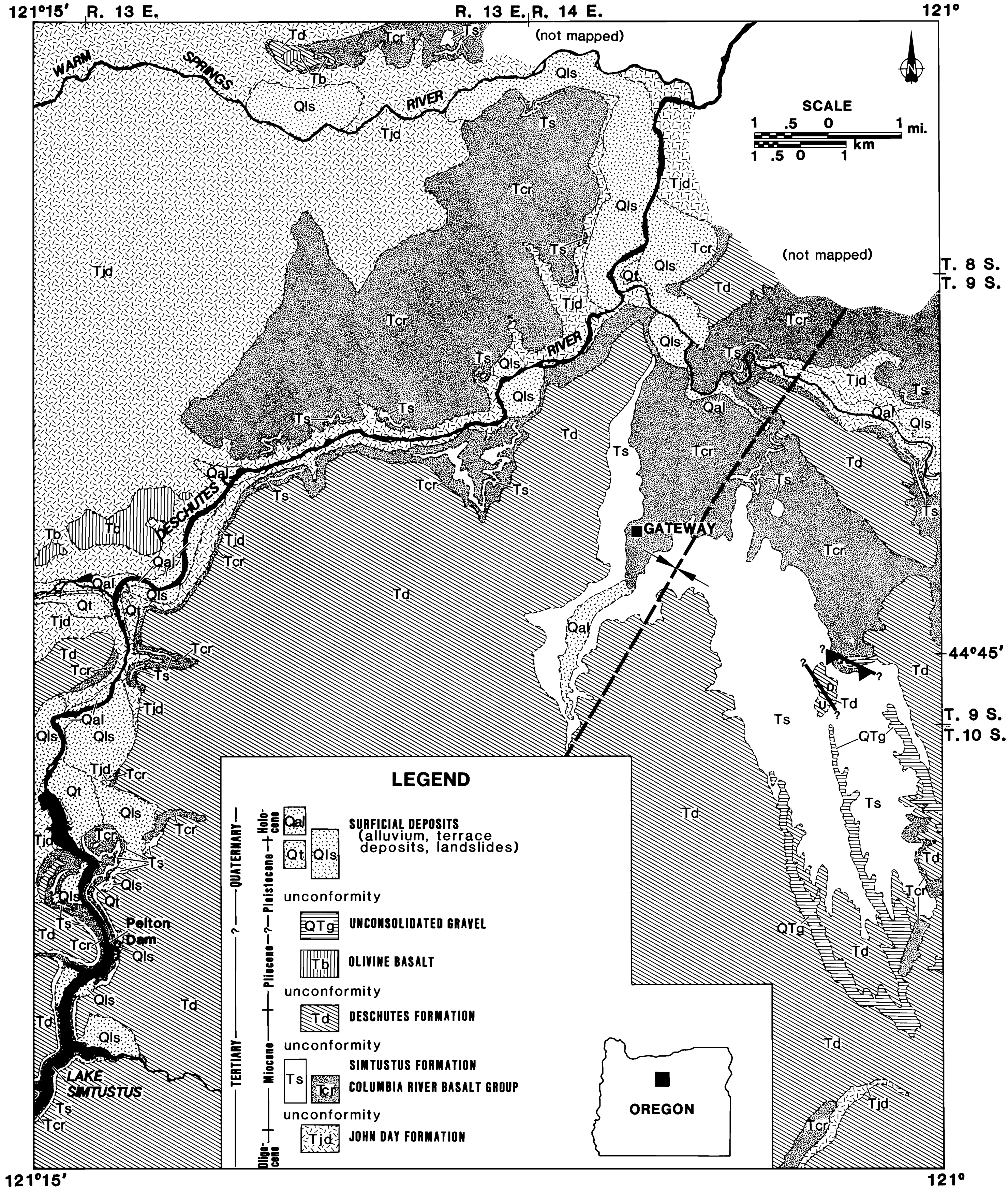

Figure 3. Geologic map of the northern Deschutes basin.

of the Deschutes basin (Nathan and Fruchter, 1974; Smith, 1986). The isotopic date is also consistent with the occurrence of the middle Miocene Pelton flora of Ashwill (1983), which is located in the lower Simtustus Formation (not in the Deschutes Formation, as reported by Ashwill, 1983). The date of the top of the Simtustus Formation, as it is preserved, is uncertain. However, less than 30 m separates Downs' (1956) pre-12-m.y. B.P. faunal localities in the upper Simtustus Formation from the unconformity with the Deschutes Formation. The 7.6-m.y.-old Pelton basalt member of the Deschutes Formation occurs near the unconformity (Figure 2; cover photo). This suggests that the preserved Simtustus Formation is entirely middle Miocene in age (12 to 15.5 m.y.) and that a hiatus of 5 m.y. or more is represented by the Simtustus-Deschutes unconformity.

FACIES ANALYSIS OF THE SIMTUSTUS FORMATION

Typical vertical sequences of lithofacies in the Simtustus Formation are represented in the measured sections (Figure 2). Two facies associations are apparent in these sections: (1) cross-bedded sandstone with minor mudstone and (2) massive mudstone and fine-grained sandstone.

The cross-bedded sandstone and minor mudstone facies are arranged in fining-upward cycles 1 to 6 m thick, averaging 2.5 m thick (Figure 4). These sequences commence with trough cross-bedded, coarse-grained, pumice-bearing sandstone or massive to horizontally stratified pebble conglomerate. The height of cross-bed sets generally decreases and the abundance of pumice lapilli increases upward in a cycle, sometimes passing into ripple cross-laminated, fine- to medium-grained sandstone. Paleocurrent directions measured from cross-bedding in both the lower and upper Simtustus Formation vary widely from N. 20° W. to N. 75° E., with mean orientations at individual locations in northeastward directions. The upper portion of each cycle is massive, light-tan, blocky jointed, fine-grained sandstone and mudstone with dispersed, rounded, pumice lapilli. This fine-grained interval frequently contains bone fragments, partial leaf and stem impressions, and rare permineralized root molds. These massive sedimentary units are interpreted as bioturbated overbank deposits.

The massive mudstone and fine-grained sandstone facies are well exposed southeast and southwest of Gateway. These deposits have much in common with inferred overbank deposits capping cycles in sandstone-dominated deposits. They are light-tan, massive, blocky jointed mudstone and fine-grained sandstone with beds of pumice lapilli interrupted by burrows and abundant lapilli dispersed through the sediment (Figures 5 and 6). Because of poor sorting, massive character, dominance of pyroclastic fragments, and dispersed pumice lapilli, these sediments closely resemble ignimbrites. However, close examination shows rare discontinuous sedimentary structures, epiclastic sandstone lenses lacking finer grained ash, and gradational lower contacts with cross-bedded sandstones. These features argue against these units being ignimbrites and suggest that the massive, poorly sorted character reflects homogenization and mixing of pyroclastic sediment by pedogenic processes. Exposures on Gateway Grade, southwest of the village, and along U.S. 97 suggest that these lithologies are organized into crude fining-upward cycles, 0.5 to 2 m thick, in which the abundance of lapilli and grain size of enclosing sediment decreases upward (Figure 5a). Bone fragments are very common, and opal-replaced *Celtis* (hackberry) endocarps are ubiquitous (Figure 6). In some localities, remnant sedimentary structures within the generally massive units are represented by thin-bedded, ripple-cross-laminated, fine-grained sandstones (Figure 5a) and plane-laminated siltstones and claystones. Clastic dikes, 1 to 2 cm wide, are filled with vertically laminated mudstone and occur in several exposures near Gateway (Figure 5b).

Volcanic debris-flow deposits have also been recognized in the Simtustus Formation. They are massive, 1 to 3 m thick, and dominated by pebble- to cobble-size clasts supported in a matrix of sand- and mud-size material. One deposit occurs north of Pelton Dam in the type section. Another occurs south and east of Gateway and contains flame structures and clastic dikes of underlying tuffaceous mudstone at its base resulting from rapid loading of saturated sediments. This latter unit thickens eastward from 1.5 m thick near Gateway to 3 m thick in Old Maids Canyon, 5 km southeast of Gateway.

The fining-upward cycles of cross-bedded sandstone to massive mudstone and highly variable paleocurrent directions are suggestive of sedimentation on point bars by meandering streams (Allen, 1964, 1970). Cross-bedded sandstone represents deposition by subaqueous dunes in the river channel and, as the channel migrated, was succeeded by fine-grained overbank

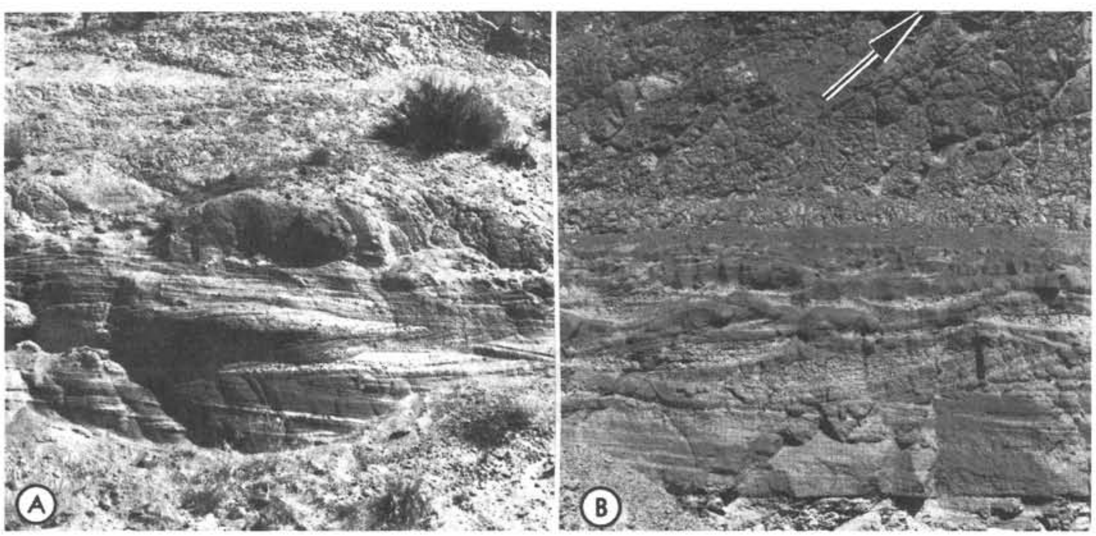

Figure 4. Upward-fining fluvial cycles in the Simtustus Formation. Each cycle commences with trough cross-bedded sandstone and grades upward into massive, blocky jointed mudstone. (a) Upper Simtustus Formation, Clark Drive, 1.0 km south of Gateway. (b) Lower Simtustus Formation at Pelton Dam. Arrow points to air-fall tuff within tuffaceous mudstone.

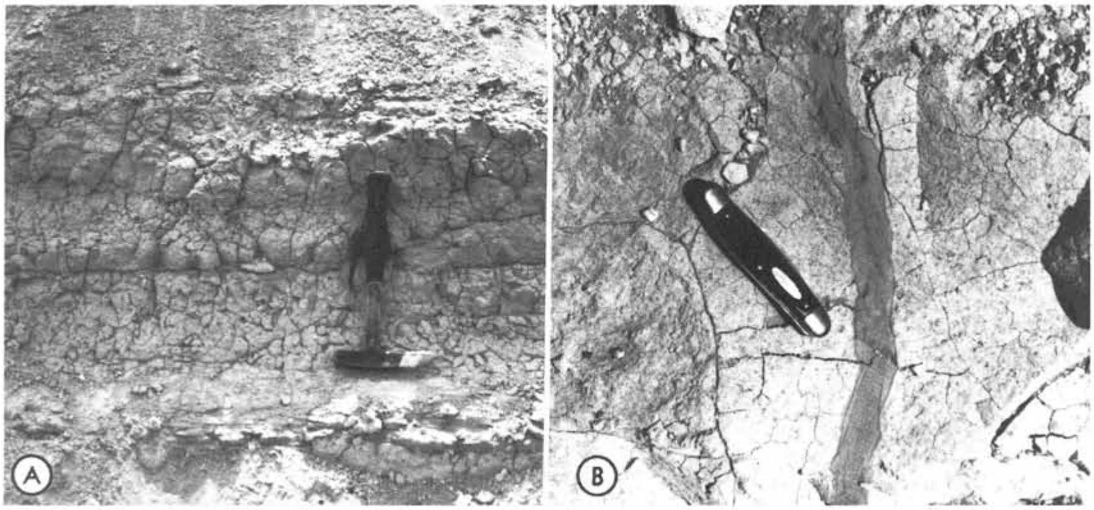

Figure 5. Outcrop photos of fine-grained sandstone and mudstone facies association. (a) Thin fining-upward sequences of ripple cross-laminated sandstone to massive mudstone; roadcut on U.S. 97, east of Gateway. (b) Clastic dike of vertically laminated mudstone cutting massive mudstone; roadcut on Gateway Grade, southwest of Gateway.

sedimentation.

The massive fine-grained sandstone- and mudstone-facies association probably represents flood-plain deposition adjacent to, but beyond the extent of lateral migration of, a river channel. This relationship is suggested by (1) bioturbation indicated by the massive character of these facies with occasional remnant structures; (2) the abundant fossil remains; (3) similarity to fine-grained upper parts of preserved point-bar facies; and (4) thickness in excess of 20 m without intervening cross-bedded sandstone or conglomerate.

PETROGRAPHY OF THE SIMTUSTUS FORMATION

Petrographic examination indicates that most Simtustus sandstones are feldspathic volcanic arenites with subordinate volcanic plagioclase arkoses and volcanic arenites (classification of Folk, 1968) and contain nearly equal proportions of pyroclastic and epiclastic volcanic fragments. Quartz and sanidine compose less than 1 volume percent of the sandstones. Heavy minerals, mostly pyroxene, hornblende, and iron-titanium oxides, are present to as much as 5 volume percent and usually display alteration rims of hematite and unidentified clay minerals.

The lithic fraction is all volcanic and, in most sandstones, consists of 50 to 75 percent slightly to highly altered, light-brown to colorless glass of coarse ash to lapilli size. Altered lapilli appear green, lavender, and pink in hand sample. This sediment was probably reworked from air-fall pyroclastics erupted in the Cascade Range and is primarily of dacitic composition (G. Hayman, personal communication, 1983). Rarely, as much as 50 percent or more of the lithic fragments are epiclastic volcanic grains. The mineralogy and texture of the epiclastic grains suggest that most are basaltic andesites and andesites derived from the Cascades, with a subordinate contribution from the interbedded Columbia River basalt (the Prineville chemical type is characterized by an abundance of groundmass apatite, making it petrographically distinct from Cascade basaltic rocks). As much as 10 percent of some sandstones consists of devitrified rhyolite grains that were probably eroded from John Day Formation rhyolite domes and ignimbrites, which likewise are the probable source of the minor quartz and sanidine. True rhyolites, with phenocrystic quartz and sanidine, are virtually unknown in the Oregon Cascades (Priest and others, 1983).

The sandstones are poorly to well cemented by opaline silica and unidentified clay minerals. Scanning electron microscope examination of one lower Simtustus sandstone also disclosed the occurrence of an unidentified, acicular zeolite. Green cryptocrystalline silica, known to local rock collectors as "wascoite," forms concretions up to 25 cm across in the lower Simtustus and also occurs as amygdules within the lower Columbia River basalt flow.

MIDDLE MIOCENE DESCHUTES BASIN PALEOGEOGRAPHY

Only a general paleogeographic picture can be constructed for the Deschutes basin during Simtustus Formation deposition because (1) exposure is restricted to the area north of Madras; (2) the main outcrop areas at Lake Simtustus and in the Gateway region are separated by an intervening area of no exposure (Figure 3); and (3) an unknown volume of the unit was removed by pre-Deschutes erosion.

The Columbia River basalt flows largely buried a terrain with erosional relief exceeding 100 m. The distribution of the lower flow was strongly controlled by the paleotopography (Smith, 1986), and lower Simtustus deposition was also largely restricted to the location of pre-existing valleys. The combined thickness of the lower basalt flow and the lower Simtustus sediment was sufficient to allow the upper flow to cover most remaining hills to produce a gently sloping plain, almost 20 km wide, on which upper Simtustus deposition occurred. Because lower Simtustus streams were confined to topographic lows, the thick flood-plain facies association is not as well represented as in the upper Simtustus Formation, where there was no confinement.

Fluvial aggradation to produce the Simtustus Formation may largely have been the result of drainage disruption by Columbia River Basalt Group lava flows (Smith, 1984). Notably, there is no record of middle Miocene deposition prior to eruption of the lowest basalt flow in the Deschutes basin, but, as discussed previously, deposition did probably commence soon after the emplacement of this flow. The two lava flows have a combined thickness of 15 m to 150 m and buried most of the paleotopography to produce a low-gradient surface on which Simtustus streams flowed. This abrupt modification of gradients could produce aggradation in a previously nondepositional system. Expected sedimentation under these conditions would be rela-

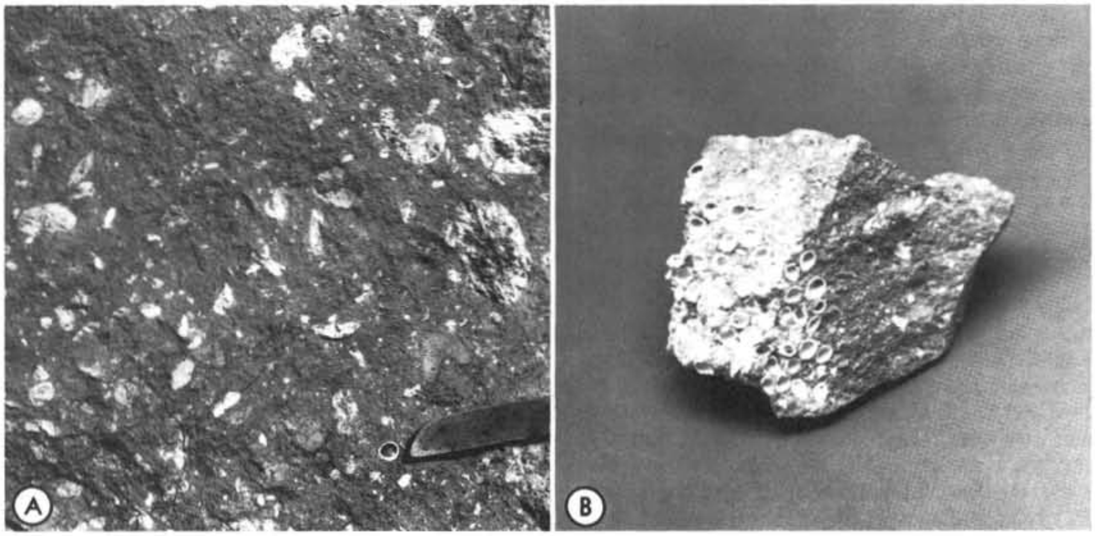

Figure 6. Photographs showing Celtis *endocarps in the Simtustus Formation. (a) Lapilli-bearing mudstone with scattered endocarps; most prominent endocarp is at tip of knife blade. (b) Hand sample of tuffaceous mudstone with numerous endocarps. Sample is 8 cm across.*

tively fine grained because of decreased competence and would include broad flood-plain deposits such as those seen in the Simtustus Formation.

Aggradation would continue until a pause of sufficient duration in basaltic volcanism occurred to allow uninhibited downcutting by the rivers. Over 200,000 km^3 of basalt of the Grande Ronde Basalt was erupted onto the Columbia Plateau between about 17.0 and 15.5 m.y. B.P. (Swanson and others, 1979). Basalt flows of the upper Grande Ronde Basalt, Wanapum Basalt (16.5 to 14.5 m.y. B.P.), and Saddle Mountains Basalt (13.5 to 6 m.y. B.P.) of the Columbia River Basalt Group are restricted north of the Deschutes basin. Although only the two flows of Prineville chemical type occur within the basin, the contemporaneous Grande Ronde Basalt inundated the ancestral Columbia and Deschutes Rivers north and downstream of the Deschutes basin, severely disrupting drainage to produce lakes adjacent to the thickening basalt plateau and raised local base level (Fecht and others, 1985).

Degradation in the Deschutes basin could commence only after headward erosion by the ancestral Columbia River progressed far enough eastward to integrate these lakes and the ancestral Deschutes River drainage. It is not clear where the confluence of the ancestral Deschutes and Columbia Rivers was at this time, but basalt distribution maps (Swanson and others, 1979) and study of the evolution of the Columbia River drainage (Anderson and Vogt, in preparation) suggest that headward incision of the ancestral streams significantly east of the Cascade Range did not occur until sometime between 14 and 12 m.y. B.P. Aggradation in the ancestral Deschutes River, imposed by flood basalt volcanism, would then extend over the period from about 16 m.y. B.P. to sometime before 12 m.y. B.P., which is consistent with available information for the age of the Simtustus Formation.

The general northeasterly course for the Deschutes River during Simtustus time, indicated by paleocurrent analysis and distribution of the interstratified basalt flows, reflects the topographic influence of the Mutton Mountains to produce an eastward deflection in the generally north-flowing river. This influence is also indicated by the Deschutes Formation paleodrainage (Smith, 1986) and modern drainage. The Mutton Mountains are a broad anticlinal uplift of east to northeast trend. However, much of the topographic relief is constructional, not structural, and is defined by a north-northeast-trending line of John Day Formation rhyolite domes. Uplift of the anticline commenced prior to the emplacement of the Columbia River basalt flows, as indicated by the underlying angular unconformity with the John Day Formation. The Prineville chemical-type basalts lapped onto the south flank of the highland, progressed around its eastern end, and spread out again to the north. Contemporary Grande Ronde Basalt flows that were erupted in northeastern Oregon and southeastern Washington onlapped the north flank of the Mutton Mountains, and some of the youngest flows extended a short distance southward around the east end of the anticline (Smith, 1986). Further uplift resulted in the angular unconformity between the Deschutes and Simtustus Formations. A broad, northeast-southwest-trending syncline with opposing dips up to 12° in the basalt is developed in the pre-Deschutes Formation rocks in the northern part of the basin (Figure 2). This syncline, south of the Mutton Mountains anticline, has apparently controlled the location of the Deschutes River since at least middle Miocene time.

RELATIONSHIP TO CASCADE VOLCANISM

Although Simtustus Formation deposition probably resulted from drainage disruption by the Columbia River basalt lavas, most of the sediment within the formation is of Cascade Range provenance. The late Western Cascade volcanic episode (18 to 9 m.y. B.P.) of Priest and others (1983) is represented in the central Oregon Western Cascades by basaltic andesite and andesite lavas with subordinate dacitic pyroclastic units (Priest and others, 1983). The Simtustus Formation, composed of primary and reworked dacitic and rhyodacitic pyroclastic material and epiclastic fragments of basaltic andesite and hornblende or pyroxene andesite, is a distal reflection of this volcanic episode.

The ratio of pyroclastic to basaltic andesite and andesite epiclastic material in the Simtustus Formation is about 2:1, although Priest and others (1983) indicate that pyroclastic material is subordinate to other lithologies in the proximal Western Cascades, which are 75 km to the west. This difference illustrates the hazards of characterizing volcanism on the basis of distal sediment composition. Pyroclastic debris is more widespread and more easily eroded than are lava flows and therefore dominates over epiclastic grains among transported sediment. However, there are also problems in assuming that proximal volcanic rocks accurately reflect the eruptive behavior of a volcanic episode. Pyroclastic material is usually unconsolidated, easily removed from steep slopes and high-gradient stream valleys typical of the proximal setting of mature volcanic arcs, and, hence, not preserved there. These characteristics tend to produce relative enrichment of pyroclastic sediment in distal depositional basins when compared with the record of pyroclastic volcanism in the source areas. It is also possible that some of the tuffaceous material in the Simtustus Formation was derived from erosion of the widespread dacitic air-fall deposits of the John Day Formation (Robinson and others, 1984).

REGIONAL STRATIGRAPHIC CORRELATION

The Simtustus Formation is the first well-studied sedimentary unit in Oregon that is interbedded with the Columbia River Basalt Group. In eastern Oregon, sedimentary interbeds within the Columbia River Basalt Group and age-equivalent Strawberry Volcanics have been recognized for their fossil floras but have generally not been named. These include sedimentary material hosting the Blue Mountains flora of Chaney and Axelrod (1959) in Grant County, 220 km east of the Deschutes basin, and the Sparta flora of Hoxie (1965) northeast of Baker, 300 km east of the Deschutes basin. Although these units are roughly contemporaneous in age and share floral elements with the Simtustus Formation, their distribution and sedimentological characteristics remain unstudied.

The Simtustus Formation is also correlative with the Mascall Formation of Merriam (1901) and Merriam and others (1925). The Mascall Formation was defined (Merriam, 1901) as a dominantly lacustrine sequence in the John Day valley, 125 km east of the Deschutes basin, where it is conformable upon and locally interfingers with the Picture Gorge Basalt of the Columbia River Basalt Group. The Picture Gorge Basalt is elsewhere intercalated with the Grande Ronde Basalt (Nathan and Fruchter, 1974). The Mascall Formation is overlain with angular unconformity by the Rattlesnake Formation of Merriam (1901) and Enlows (1976) (redefined as the Rattlesnake Ash-flow Tuff and unnamed conglomerate by Walker[1979]), which is dated at about 6.6 m.y. B.P. (Enlows, 1976). The Rattlesnake ignimbrite is also interbedded with the Deschutes Formation in the eastern Deschutes basin (Smith and others, 1984; Smith, 1986). The Simtustus and Mascall Formations thus share a similar structural and stratigraphic position relative to the Columbia River Basalt Group and overlying upper Miocene rocks and also share a similar vertebrate fauna (Downs, 1956).

Unnamed sedimentary rocks with Mascall faunal components (Downs, 1956) or similar stratigraphic position occur at several localities east of the Deschutes basin (Walker, 1977) and are probably generally correlative with the Simtustus Formation. Until more sedimentologic and stratigraphic work is done, it seems prudent to restrict the name Mascall Formation to the dominantly lacustrine, pyroclastic sediments of the John Day basin, to restrict Simtustus Formation to the dominantly fluvial, mixed pyroclastic and epiclastic sediments of the Deschutes basin, and to leave other middle Miocene volcaniclastic rocks unassigned at this time.

The absence of rocks of lacustrine origin within the Simtustus Formation indicates that the Deschutes basin was not a closed basin at that time. Therefore, deposits of the aggrading fluvial system with characteristics similar to the Simtustus Formation can be expected to occur farther north and have been recognized during reconnaissance investigations. In Cow Canyon, 30 km northeast of Madras, fluvially deposited sediments that are lithologically identical to the Simtustus Formation occur between a Prineville chemical-type basalt flow and a high-MgO Grande Ronde Basalt flow, probably from the upper half of the Grande Ronde section (Swanson and others, 1979). Similar interbeds occur with Prineville chemical-type and low-MgO Grande Ronde flows on the north flank of the Mutton Mountains; one of these interbeds hosts the Foreman Point flora of Ashwill (1983). In Butler Canyon on Tygh Ridge, 70 km north of Madras, two Prineville chemical-type flows, believed to be the same two as in the Deschutes basin (Smith, 1986), are separated by four low-MgO Grande Ronde Basalt flows (Nathan and Fruchter, 1974). Two sedimentary interbeds lithologically similar to the Simtustus Formation occur within this interval and are correlative to the lower Simtustus in the Deschutes basin. Similar tuffaceous sediments occur as interbeds higher in the Columbia River Basalt Group section on Tygh Ridge and also conformably above the basalt. The sediments conformable upon the basalt (mapped as Ellensburg Formation by Waters, 1968b) are lithologically distinct from the overlying sediments of the Dalles Formation of Waters (1968b) or Tygh Valley Formation of Farooqui and others (1981a) and are separated from them by a 40° angular unconformity. The sediments conformable upon the basalt should not be included in the Tygh Valley Formation of Farooqui and others (1981a). Thin, laminated mudstones occur between Grande Ronde flows on the north flank of Tygh Ridge and probably represent the lakes into which the ancestral Deschutes River flowed. Formal stratigraphic designation of these sedimentary units should await more detailed study, but the observations described above indicate northward continuation of the Simtustus Formation lithosome and suggest that the Simtustus Formation overlying the Prineville chemical-type lavas in the Deschutes basin is intercalated with younger Columbia River basalt flows to the north.

Beyond north-central Oregon, the Simtustus Formation is correlative to middle Miocene sedimentary units that are interbedded with the Columbia River Basalt Group in Washington and with others in the Basin and Range province in southeastern Oregon. The Ellensburg Formation and Latah Formation are interbedded with and locally overlie the Columbia River Basalt Group in central Washington and northeastern Washington and adjacent Idaho (Swanson and others, 1979). The Ellensburg Formation, as redefined by Swanson and others (1979) to include all sedimentary interbeds within the basalt and sediments above the basalt in the western Columbia Plateau in Washington, is a lithologically diverse unit of volcanogenic and arkosic fluvial and lacustrine sediments (Mackin, 1961; Schmincke, 1964) that locally accumulated to great thickness in basins of the Yakima fold belt. The Ellensburg Formation is also interbedded with and overlies Wanapum and Saddle Mountains Basalt and contains a Hemphillian fauna near Yakima (Martin, 1979); therefore only the lower part is correlative with the Simtustus Formation. The Latah Formation is composed of fine-grained arkosic sediments primarily deposited in lakes (Pardee and Bryan, 1926) that formed along the eastern margin of the basalt plateau, presumably because of drainage disruption by the lava flows.

Based on similar fauna and flora, the Simtustus Formation is also correlative, in part or whole, with the Sucker Creek Formation, Deer Butte Formation, Drip Spring Formation, and Butte Creek Volcanic Sandstone and interbedded basalts, rhyolites and ignimbrites in southeastern Oregon of Kittleman and others (1965). These volcanogenic and arkosic sediments filled fault-bounded basins in the Basin and Range province.

CONCLUSIONS

The Tertiary nonmarine sedimentary rocks of central and eastern Oregon require detailed study to obtain useful stratigraphic and sedimentologic information necessary to evaluate the stratigraphic nomenclature, paleogeography, and tectonic development of the region. In over eighty years of geologic endeavor in the Deschutes basin, almost a dozen workers failed to recognize the occurrence of an unconformity within the sedimentary rocks overlying the Columbia River Basalt Group. This oversight reflects the reconnaissance nature typical of most stratigraphic studies in the eastern two-thirds of the state. Detailed stratigraphic study indicates that this unconformity, representing a depositional hiatus of 5 m.y. or more, separates two lithologically distinct volcaniclastic sequences with largely Cascade provenance, the newly defined Simtustus Formation, and revised Deschutes Formation.

The Simtustus Formation represents channel and flood-plain deposition by low-gradient, mixed-load, possibly highly sinuous streams. Based upon compelling circumstantial evidence, aggradation primarily resulted from drainage disruption and gradient diminishment by basalt flows of the Columbia River Basalt Group with which the Simtustus Formation is demonstrably contemporaneous. Basin analysis of the Simtustus Formation and distribution of intercalated Grande Ronde Basalt (Prineville chemical type) suggest that uplift of the Mutton Mountains had commenced prior to the middle Miocene and has influenced the regional drainage pattern since that time.

The Simtustus Formation is the first well-studied sedimentary unit in Oregon that interfingers with the Columbia River Basalt Group. Other sedimentary units interbedded with these basalts in Oregon are unnamed, with the exception of the Mascall Formation, and known only for their faunal and floral constituents. The sedimentary rocks interbedded with the Columbia River Basalt Group on most of the Washington portion of the Columbia Plateau are assigned to the Ellensburg or Latah Formation and are lithologically distinct from the only partly age-equivalent rocks in the Deschutes basin, warranting use of a separate name. Following the practice of Schmincke (1964) and Swanson and others (1979) in Washington, sediment interbedded with the Columbia River basalt in the Deschutes basin is assigned to the overlying Simtustus Formation because it cannot be lithologically distinguished from the volcaniclastic rocks conformable above the basalt.

Subdivision of sedimentary units deposited contemporaneously with the Columbia River Basalt Group on the basis of stratigraphic position relative to the named basalt members is not perpetuated because of potential ambiguity when definitive basalts do not occur in a sedimentary sequence. The author hopes that future stratigraphic assignments of interbedded sedimentary units will be based upon the lithostratigraphic character of the sedimentary rocks alone, regardless of the basalts with which they are associated. Relative to this problem, it is notable that while most of the type Simtustus Formation overlies the Columbia River Basalt Group in the Deschutes basin, at the plateau margin, it probably interfingers with younger flows northward toward the plateau interior. Reconnaissance observations suggest continuation of the Simtustus Formation at least as far north as Tygh Ridge, but stratigraphic assignments of volcanogenic sedimentary rocks interbedded with the Columbia River basalt north of the Deschutes basin is left for future detailed work.

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Atlas of West Coast seafloor released

An atlas of the U.S. deep-water seafloor off the West Coast, the first extensive seafloor atlas of its kind, has been published by the U.S. Geological Survey (USGS).

The atlas represents the marriage of unique sonar technology developed by the British Institute of Oceanographic Sciences (IOS) and computer-enhanced mapping techniques developed by the U.S. Geological Survey as part of the U.S. space program. The 152-page atlas will help delineate potential energy and mineral resource targets and also reveals dozens of previously unmapped submarine volcanoes, landslides, faults, and other features.

The sonar system -- called GLORIA -- developed by IOS is capable of mapping up to 10,500 square miles a day, an area roughly equivalent to the size of New Jersey or Maryland. The sonar mosaic maps published in the atlas were enhanced through cartographic and computer techniques developed by the USGS as part of the space program effort to map the geology of the moon and the planets. Opposite each mosaic sheet in the atlas is another sheet at the same scale (1:500,000; one inch equals 8 miles) showing some of the preliminary geologic interpretation and bathymetry. Two other sections in the atlas provide a three-dimensional glimpse of the seafloor geology using seismic reflection and residual magnetic anomaly data collected at the same time as the sonar data.

Copies of the atlas, titled "Atlas of the Exclusive Economic Zone, Western Conterminous United States," and published as USGS Miscellaneous Investigations Series I-1792, may be purchased for $45 each from the Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, Colo. 80225, telephone (303) 236-7477. When ordering by mail, please include both the atlas number (I-1792) and title and check or money order payable to Department of the Interior-USGS.

— *USGS press release*

ABSTRACTS

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

PALEOMAGNETISM, ROCK MAGNETISM, AND DIAGENESIS IN HEMIPELAGIC SEDIMENTS FROM THE NORTHEAST PACIFIC OCEAN AND THE GULF OF CALIFORNIA, by Robert Karlin (Ph.D., Oregon State University, 1984 [dissertation compl. 1983])

Downcore magnetic profiles from undisturbed Kasten cores taken in rapidly deposited laminated sediments from the Gulf of California and in bioturbated hemipelagic muds on the Oregon continental slope give apparently reliable directions, but show dramatic decreases in the intensities of natural (NRM) and artificial (ARM, IRM) remanences with depth. Downcore porewater and solid sulfur analyses show concave-down decreases in porewater sulfate and systematic increases in pyrite and metastable monosulfides. The maximum curvature of the sulfide profiles occurs directly below the high magnetization zone. Combined with other compositional and mineralogic analyses, these data suggest that, due to oxidative decomposition of organic matter, magnetites and other iron oxides become progressively reduced and subsequently sulfidized and pyritized with depth. Iron reduction seems to occur prior to sulfide formation. Changes in magnetic stability parameters are consistent with selective dissolution of the finer sized grains causing downcore coarsening of the magnetic fraction.

Paleomagnetic directions from the Oregon sediments show exceptional directional stability and provide a detailed record of geomagnetic secular variation for the past 3,000 years. When compared to secular variation studies from other regions, directional fluctuations show good coherence and time delays consistent with a constant westward drift having a periodicity of 1,200 years which has continued for at least the last 3,000 years. A maximum correlation analysis with a zonal drift model of the present field lends support to this hypothesis.

Paleomagnetic measurements on a 152-m sedimentary section taken with a Hydraulic Piston Corer at DSDP Site 480 in the Gulf of California yield an almost continuous secular variation record for the past 200-300 Ky. Initial results show no major zones of reversed polarity, and the core and site mean inclinations are not significantly different than the expected geocentric axial dipole inclination. The similarity of mean inclinations in laminated, homogeneous, and mottled sediment lithologies suggests that remanence was acquired below the active zone of bioturbation.

SEDIMENTATION, STRUCTURE, AND TECTONICS OF THE UMPQUA GROUP (PALEOCENE TO EARLY EOCENE), SOUTHWESTERN OREGON, by Paul Thomas Ryberg (Ph.D., University of Arizona, 1984)

A major change in sedimentary and structural style occurs in Eocene strata exposed along the southern margin of the Oregon Coast Range. Lithofacies of the early Tertiary Umpqua Group have been described, mapped, and assigned to likely depositional environments. Submarine fan and slope facies (upper Roseburg Formation) overlie Paleocene basaltic basement rocks to the north, whereas fluvial, deltaic, and shallow-marine facies (Lookingglass Formation) overlie Franciscan-equivalent strata to the south along the flank of the Klamath Mountains. These two depositional systems are gradational into one another, and were prograding northwestward until about 52 m.y. B.P. Means of clast compositions from sandstones and conglomerates from both the Roseburg and Lookingglass Formations suggest derivation from identical recycled orogen or arc-continent collision sources in the Klamath Mountains.

Change from Klamath-parallel to more north-south structural trends is well displayed within early Eocene strata of the Umpqua Group. Five major fault systems involve lower Umpqua (Roseburg and Lookingglass) strata and were active while deposition was taking place. All these faults ceased to be active at about 52-50 m.y. B.P. and are overlapped by the middle Eocene Tyee Formation. Regional strain analysis indicates more than 20 percent shortening by right-lateral convergence during early Eocene time.

The structural style and syntectonic deformation of marine slope facies suggest deposition in an active subduction complex until about 52 m.y. B.P. Structural trends in the Southern Oregon Coast Range parallel those in the adjacent Klamath Mountains until the end of the early Eocene. At 52-50 m.y. B.P., subduction apparently ceased as incoming seamounts clogged the trench and may have jumped to an outboard position near the present-day coastline. In middle Eocene time, the newly developed forearc region rapidly filled with sediments from a much sandier depositional system.

Paleomagnetic studies of relatively undeformed Tyee forearc strata indicate as much clockwise rotation as the much more deformed, underlying volcanic basement of the Oregon Coast Range. Rotation of the Oregon Coast Range as a single crustal block must have occurred after, rather than during, seamount accretion to the continental margin, which was essentially complete by 52 m.y. B.P.

GEOLOGY OF THE NORTHEAST ONE-QUARTER OF THE PRINEVILLE QUADRANGLE, NORTH-CENTRAL OREGON, by Neil J. Bingert (M.S., Oregon State University, 1984)

The project area is located in north-central Oregon approximately 8 km north of the city of Prineville. The most widespread geologic unit found in the project area is the Clarno Formation. The Clarno Formation has been subdivided into two main mappable units: a lower member and an upper member. This division is based on the occurrence of a thick, extensive saprolite between the two members. The lower member is composed of coarsely porphyritic domes and flows of rhyodacitic to andesitic composition. All of the lower member lavas contain phenocrysts of plagioclase, clinopyroxene, orthopyroxene, and quartz. Hornblende is an additional phase found in the rhyodacites. The upper member contains flows and domes of fine-grained nonporphyritic to coarsely porphyritic lavas of predominantly andesitic composition. Basalts and basaltic andesites are subordinate. The major phenocrystic phases found in most upper-member lavas include plagioclase, clinopyroxene, and orthopyroxene. In addition, several contain phenocrysts of quartz, olivine, or hornblende. The upper member has been further subdivided by separately mapping hornblende-bearing dacites and rocks of rhyodacitic composition. The hornblende-bearing dacites occur as a chain of east-west trending domes with associated short, thick, autobrecciated flows. Rocks of rhyodacitic composition within the upper member include two domes and one extensive xenolith-bearing flow.

In addition to the Clarno Formation, the project area also contains outcrops of John Day Formation, two units of undetermined age, and various Quaternary alluvium deposits. The John Day Formation has been subdivided into two mappable units including a welded ash-flow tuff and exposures of tuffaceous claystones. The rocks of undetermined age include a welded ash-flow tuff and an olivine basalt flow.

The entire project area lies on the southern limb of the Blue Mountain anticline. All of the dips in the area are gentle. Only two faults have been positively identified in the area. Both trend east-west and appear to be of the normal type with only minor displacement.

STRUCTURAL GEOLOGY OF THE RASTUS MOUNTAIN AREA, EAST-CENTRAL OREGON, by Kenneth R. Engh (M.S, Washington State University, 1984)

The Rastus Mountain area lies within the Ironside Mountain inlier of eastern Oregon. The inlier contains rocks of Mesozoic age and is surrounded by a Tertiary volcanic and sedimentary cover. Pre-Tertiary rocks in the Rastus Mountain area are represented by the Early to Middle Jurassic Weatherby Formation.

The Weatherby Formation has been tightly folded into northwest- to southeast-trending asymmetric chevron-shaped folds with a pervasive axial planar cleavage. The folds have a 28° interlimb angle, subhorizontal axes, and axial planes that dip approximately 70°/71° SE.

The Weatherby has undergone shortening of at least 35 percent perpendicular to the axial plane of the folds. Precise determination of the amount of strain is complicated by pressure solution which played a large role in the formation of the axial planar cleavage.

Deformation of the Weatherby probably occurred in the Late Jurassic, marking the end of deposition in the basin.

The Weatherby Formation consists dominantly of calcareous gravity flow deposits containing abundant volcanic rock fragments. These rocks were probably deposited in a forearc basin and are allochthonous. Approximately 750 m of the Weatherby Formation is exposed in the Rastus Mountain area.

The Weatherby Formation has been intruded by granodioritic to granitic stocks and dikes. The dikes are surrounded by a 500-m contact metamorphic aureole. Rock types within the aureole include skarn, marble, and hornfels. □

OIL AND GAS NEWS

Oregon Natural Gas begins preparation for gas storage

In late April, Oregon Natural Gas Development Corp. began preparation for gas storage by perforating an existing well in the Bruer Pool. The well, Columbia County 32-10, was drilled in 1981 by Reichhold Energy in sec. 10, T. 6 N., R. 5 W., as a deep test below the pool. It has been suspended since that time. By perforating the Clark and Wilson storage zone, the present operator now has made a fourth well available for storage in the pool. Additional storage and monitor wells will be drilled in the future.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
357	Hutchins & Marrs Georgia Pacific 2 011-00023	NE¼ sec. 14 T. 30 S., R. 10 W. Coos County	Application; 6,000.
358	Damon Petroleum Stauffer Farms 35-1 047-00020	NW¼ sec. 35 T. 4 S., R. 1 W. Marion County	Application; 2,800.
359	ARCO Crown Zellerbach 21-22 009-00196	NW¼ sec. 22 T. 5 N., R. 4 W. Columbia County	Application; 3,315.
360	ARCO Columbia County 42-8 009-00197	NE¼ sec. 8 T. 5 N., R. 5 W. Columbia County	Application; 1,730.
361	ARCO Columbia County 12-6 009-00198	NW¼ sec. 6 T. 5 N., R. 5 W. Columbia County	Application; 1,830

□

Landslides underestimated

Expert geologists point out that damages and losses caused by landslides are often overlooked or underestimated. In many cases, they are small, occur in isolated areas, and do not receive much public attention or news coverage. Yet, their cumulative effect makes them the most costly natural disasters in the nation.

Three recent examples illustrate the destructive potential of landslides: (1) On October 7, 1985, a landslide on a densely populated hillside at Mameyes, Puerto Rico, destroyed more than 100 homes and killed more than 125 people, after heavy rains from tropical storm Isabel had made the slope unstable. (2) During the eruption of Nevado del Ruiz in Colombia on November 13, 1985, hot volcanic materials melted ice and snow masses, thus causing mudflows that inundated communities and killed more than 20,000 people. (3) Persistent storms battered California and other western states in February 1986, creating numerous land- slides on water-soaked hillsides that caused millions of dollars in damage.

The following points were made by Darrell Herd, chief of the U.S. Geological Survey (USGS) land-slide program, and by USGS landslide experts Robert L. Schuster and Robert W. Fleming:

- While the examples above are not typical of the landslide damage sustained each year, the death toll from landslides in the United States averages about 20-25 deaths per year.
- Direct and indirect costs to public and private property run into the billions of dollars worldwide and average an estimated $1.5 billion per year in the U.S.
- Direct and indirect losses from landslides in the U.S. each year are about equal to the direct property losses from earthquakes in the U.S. over the past 20 years combined.
- In addition to killing people and livestock and damaging or destroying buildings and other facilities, slope failures are destructive to agricultural and forest lands and impair the quality of water in rivers and streams. Indirect costs of landslides include such things as loss of productivity of agricultural and forest lands, reduced real estate values, loss of productivity and wages in industries hit by landslides, and loss of property tax revenues. Such indirect costs may exceed the direct costs.
- The most expensive landslide in U.S. history occurred in 1983, blocking Spanish Fork Canyon at Thistle, Utah. The landslide dam formed a large lake, causing the town of Thistle to be flooded and blocking two major highways and a rail line through the canyon. Losses were estimated at $250 million.
- How landslide losses are often greater than is generally recognized is illustrated by the tremendous destruction in central Virginia in 1969 that is remembered as an effect of Hurricane Camille. In fact, most of the 150 people killed during the storm died in debris flows caused by the heavy rains.
- While most landslides still occur in unpopulated areas, a growing number hits populated areas as construction expands into landslide-prone hillside areas. Human activity disturbs large volumes of earth and rock in construction of highways, buildings, mines, dams, and other facilities and has become a major factor in an increase in landslides.
- In order to anticipate extensive landsliding such as occurred in California earlier this year, the USGS has set up a rain-gauge network that can alert to rainfall amounts that might trigger landslides. The USGS, then, gives information to the National Weather Service, which, in turn, can issue special landslide advisories to the public in conjunction with its weather reports. — *USGS news release*

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