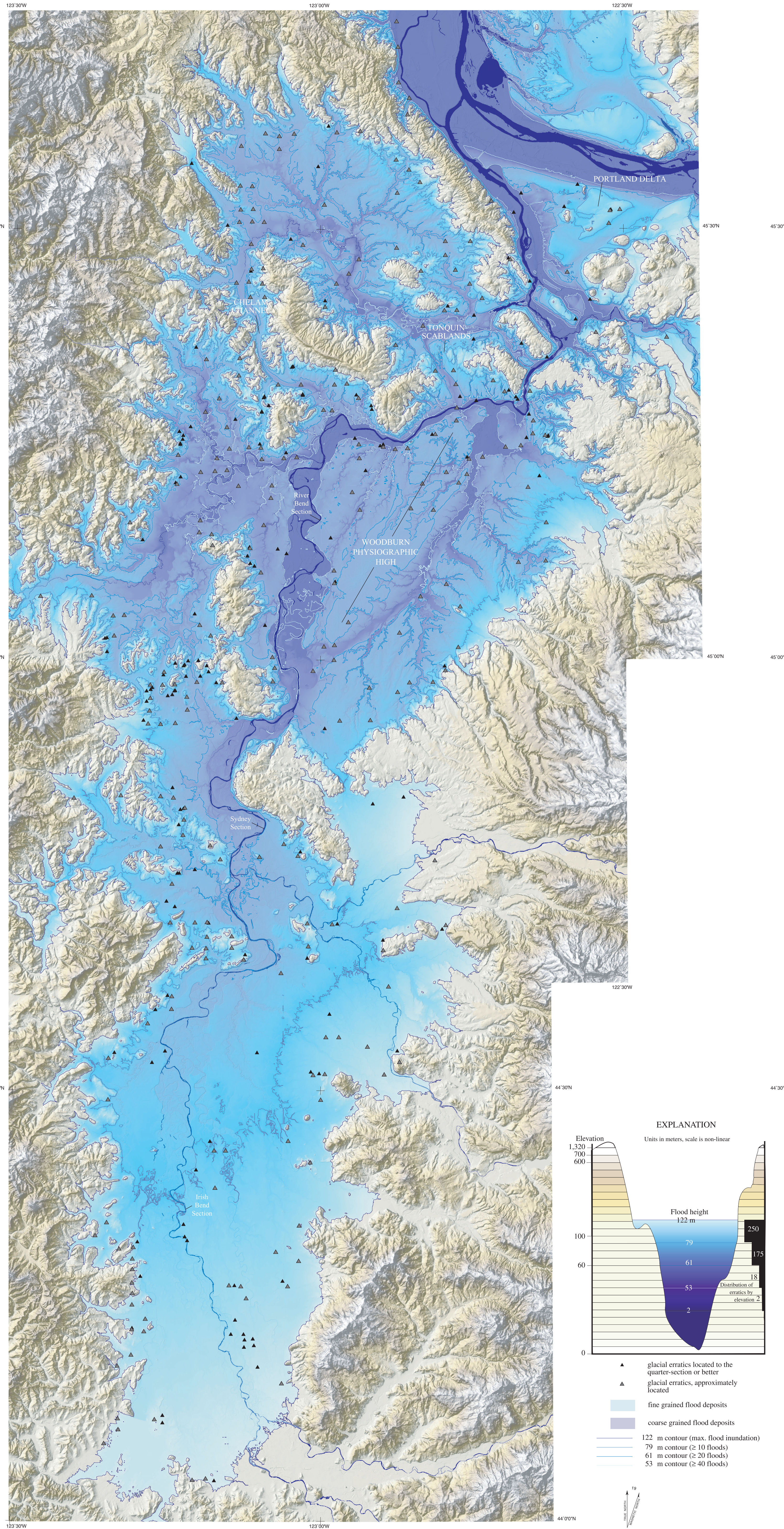
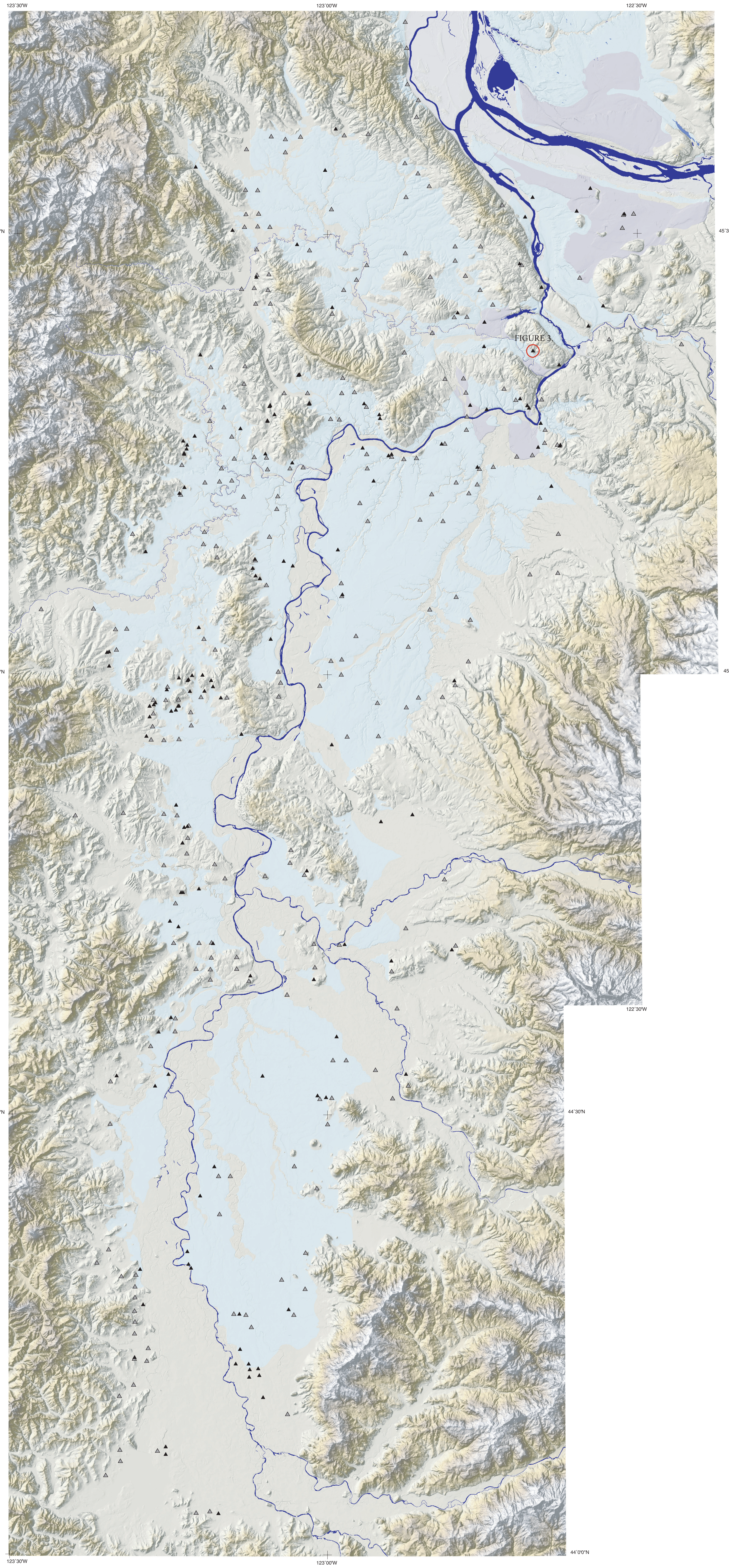
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 03-408



Inundation depths and limits



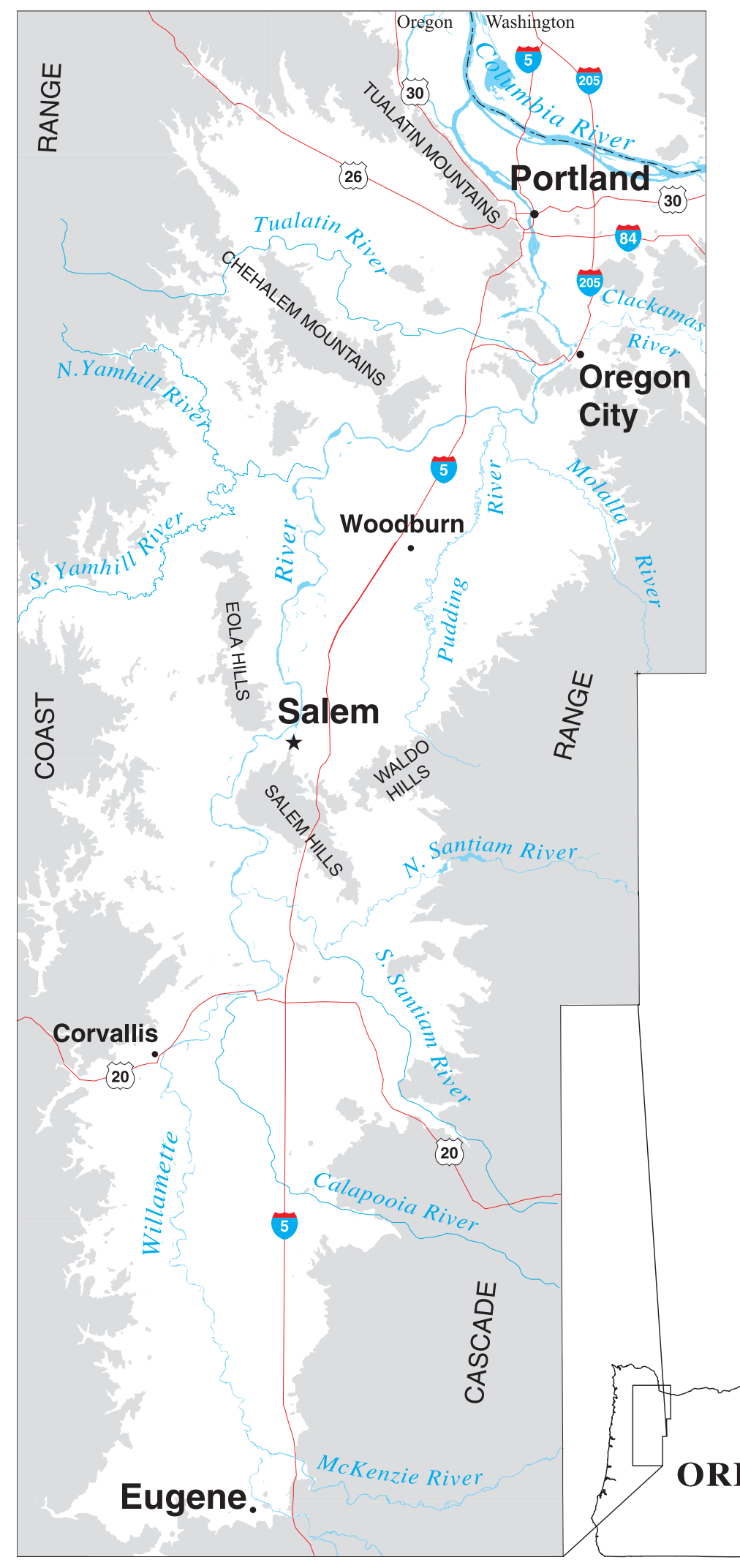
Sedimentary deposits

19
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1999

SCALE 1:250 000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 KILOMETERS



Index map showing geographic and cultural features mentioned in text.

Abstract

Glacial Lake Missoula, impounded by the Purcell Trench lobe of the late Pleistocene Cordilleran Icesheet, repeatedly breached its ice dam, sending floods as large as 2,500 cubic kilometers racing across the Channeled Scabland and down the Columbia River valley to the Pacific Ocean. Peak discharges for some floods exceeded 20 million cubic meters per second. At valley constrictions along the flood route, floodwaters temporarily ponded behind each narrow zone. One such constriction at Kalama Gap—northwest of Portland—backed water 120-150 meters high in the Portland basin, and backflooded 200 km south into Willamette Valley. Dozens of floods backed up into the Willamette Valley, eroding "scabland" channels, and depositing giant boulder gravel bars in areas of vigorous currents as well as bedded flood sand and silt in backwater areas. Also, large chunks of ice entrained from the breached glacier dam rafted hundreds of "erratic" rocks, leaving them scattered among the flanking foothills and valley bottom. From several sources and our own mapping, we have compiled information on many of these features and depict them on physiographic maps derived from digital elevation models of the Portland Basin and Willamette Valley. These maps show maximum flood inundation levels, inundation levels associated with stratigraphic evidence of repeated floodings, distribution of flood deposits, and sites of ice-rafted erratics. Accompanying these maps, a database lists locations, elevations, and descriptions of approximately 400 ice-rafted erratics—most compiled from early 20th-century maps and notes of A.M. Piper and I.S. Allison.

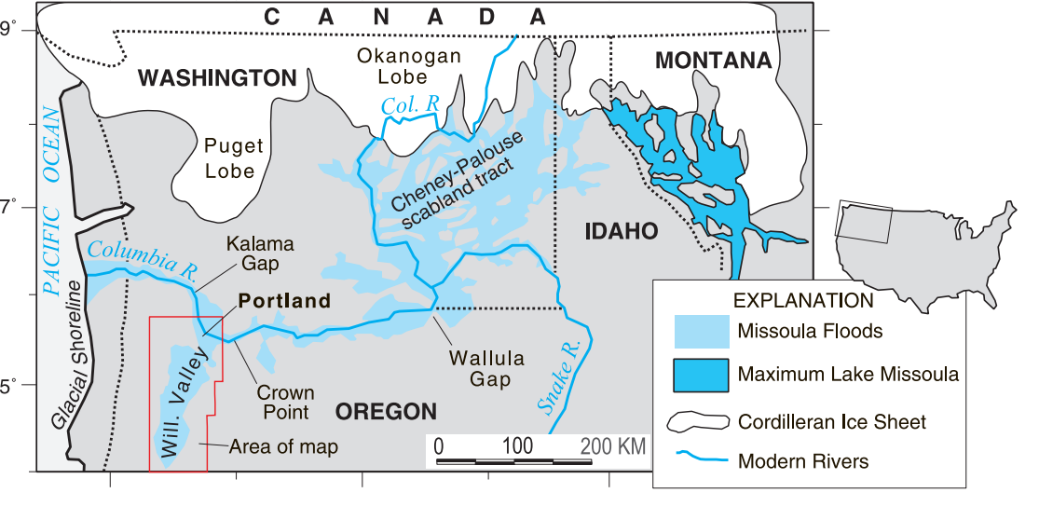


Figure 1. The Pacific Northwest region during the Late Pleistocene Missoula Floods (after Benito and O'Connor, 2003).

Introduction

During the last North American glacial maximum between 15,000 and 20,000 years ago, the southward advancing Cordilleran ice sheet dammed the Clark Fork River valley in western Montana, creating glacial Lake Missoula. At its maximum extent Glacial Lake Missoula (fig. 1) covered 7,400 square kilometers and contained 2,200 cubic kilometers of water behind an ice dam at least 525 meters high. The impounded lake breached the ice dam scores of times, sending what were some of the planet's largest known floods racing across Idaho, eastern Washington, and down the Columbia River Valley to the Pacific Ocean (Bretz, 1925, 1969; Baker, 1973; Waitt, 1980; 1985). At valley constrictions along the flood route, flood water formed temporary upstream lakes as it funneled through each narrow zone. One such constriction was at Kalama Gap, northwest of Portland, which backed water up into the Portland basin and southward into the Willamette Valley (Glenn, 1965; Allison, 1978). In the Willamette Valley and elsewhere, the dozens of floods caused by repeated breaching of the ice dam resulted in eroded "scabland" channels, giant boulder and gravel bars, bedded flood sands and silts in backwater areas, and hundreds of "erratic" rocks rafted to their present positions on large chunks of ice broken from the breached glacier dam (Allison, 1935; Glenn, 1965; Waitt, 1985; Atwater, 1986; O'Connor and others, 2001; Benito and O'Connor, 2003).

Glacial Erratics in the Willamette Valley

Rocks of erratic lithology-that is, types not typically found in western Oregon, notably granitic and metamorphic rocks-probably damaged the spades and plows of the first French Canadian and Oregon Trail settlers to till the fertile silt of the Willamette Valley in the early 19th century. In an 1883 lecture, however, Thomas Condon was the first scientist to refer to these erratic rocks (reprinted in Condon, 1902). The first systematic description of glacial erratics in the Portland basin and Willamette Valley was in 1895 by Joseph S. Diller, who inferred they were carried by icebergs to the shores of a "Willamette Sound" during Pleistocene submergence of the Willamette Valley. Subsequently, Arthur M. Piper, followed by Ira S. Allison, in the late 1920s and early 1930s made the most extensive known inventories of erratics in the Willamette Valley. Allison's observations were published in 1935, but Piper only briefly mentions the information he collected about glacial erratics in his 1942 report on the Willamette Valley. Allison in particular attributed the erratic rocks to ice-rafting during temporary inundation of the Willamette Valley during the Missoula Floods, noting that the distribution of glacial erratics and flood-lain silt indicate flood waters covered the Willamette Valley to an elevation of 122 m (400 ft) above sea level and as far south as Eugene.

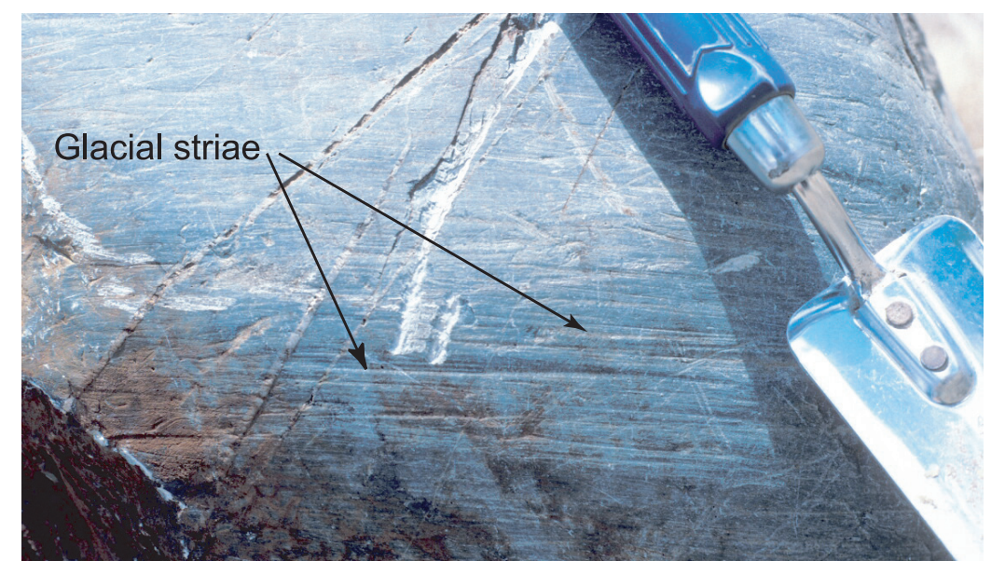


Figure 2. Striations on this Willamette Valley glacial erratic reflect its glacial origin and are consistent with ice-rafted transport to the valley.

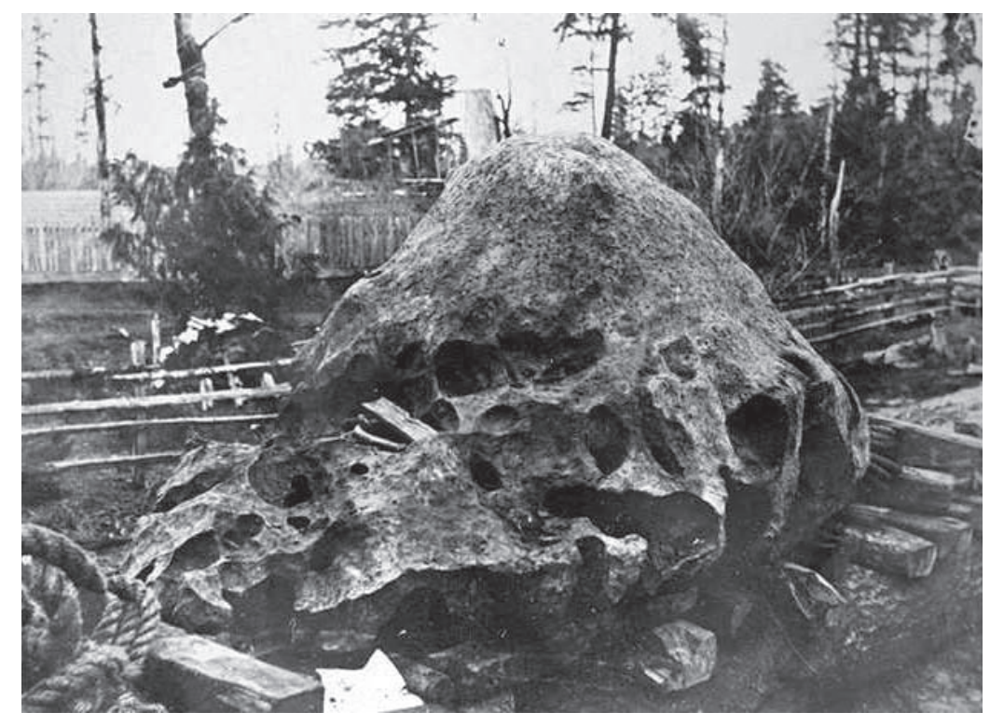


Figure 3. The Willamette Meteorite is the largest meteorite ever discovered in the United States. It is now on display in the American Museum of Natural History in New York City. Although the meteorite was discovered on a hilltop in the Willamette Valley, scientists believe the 15.5 ton iron-nickel mass landed on the Cordielleran ice sheet in British Columbia before being carried southward by the advancing ice sheet and floated into the Willamette Valley embeded in an iceberg during Missoula Floods. (Photo from the Lake Oswego Public Library miscellaneous historic photos collection: http://www.ci.oswego.or.us/photos/Disk6/IMG0007.JPG)

Subsequent geologists and interested lay people have continued to discover these erratics, but even more seem to be disappearing by urbanization, collecting, and blasting. In order to preserve as much of this information as possible, we have compiled a digital database of glacial erratic locations from available notes and publications. Locations are plotted on the accompanying physiographic map of the Willamette Valley and Portland basin. The vast majority of these glacial erratics are no longer present. Along with the map of glacial erratic locations, we also show the present distribution of mapped Missoula Flood deposits, examples of specific physiographic features left by the floods, and four specific inundation levels associated with evidence of multiple flooding.

Description of erratics

Glacial erratics in the Willamette Valley are mostly pebble- to small boulder-sized rocks with diverse lithologies, including basalt, granite, granodiorite, sandstone, quartzite, schist, gneiss, diorite, slate, and rhyolite. The granitic and metamorphic rock types are quite distinct from the fine-grained volcanic rocks and sedimentary rocks which compose the bedrock of western Oregon. Specimens are commonly faceted and some are striated and polished, indicating glacial transport (fig. 2). Glacial erratics are typically found on topographic highs and valley slopes, where one could imagine icebergs becoming stranded during receding floodwater. The summits and shoulders of low hills commonly contain dozens of cobble-sized erratics, and farmers frequently pull or blast large erratics from their fields. Abundant cobble and smaller-sized erratics can typically be found near larger erratics, indicating stranding of a large, debris-laden piece of ice. Some erratics are preserved in exposures of the flood silts that underlie much of the valley bottom. The vast majority of erratics lie below 122 m above sea level; however, Piper (1942) noted boulders "widely scattered in valleys and on tops of hills and knolls 800-1,500 ft. [244-457 m] high" eight miles south of Portland, near Prosser mine, east of Lake Oswego. This location has not been confirmed. Allison (1935) described "A half dozen small [erratics], ranging in size up to 8 inches [20 cm] lying on Judkin's Point, Eugene, Oregon, at an altitude of about 650 feet [198 m] above sea level, are so far above any other known occurrence that their authenticity is doubtful." Allison attributes the high elevations of these erratics to transport by Native Americans.

Two of the most remarkable glacial erratics are the 'Willamette Meteorite' and the 'Sheridan' erratic. The Willamette Meteorite (fig. 3) is a 14.1 tonne iron-nickel meteorite, the largest meteorite ever found in the United States, and was discovered in 1902 atop a 160 m hill just south of Portland (Pugh, 1986). The absence of an impact crater at the original location of 3-m-long, 1.2-m-high, bell-shaped meteorite suggests it did not collide with the Earth in the Willamette Valley. Moreover, the topographic position of the meteorite, and several pebble to boulder-sized erratics of other lithologies found in and around the area from which the meteorite was removed, are consistent with an ice-rafted origin. The Sheridan erratic is a 160-ton argillite boulder resting on a 93 m knob southwest of McMinnville on state highway 18 (Allen and others, 1986). The Sheridan erratic now sits in several large pieces, the largest of which being 5.4 x 3.9 x 1.5 m. Upon discovery, however, its dimensions were 6.3 x 5.4 x 1.5 m, indicating that collectors have removed a significant volume of this erratic (Allen and others, 1986).

The glacial erratic database

Known erratic locations in the Willamette Valley come from a variety of published and unpublished sources. Arthur M. Piper cataloged field observations (mostly during 1928 and 1929) and literature citations of glacial erratics in the Willamette Valley and Portland basin in a series of 82 index cards and accompanying field maps archived at the U.S. Geological Survey Water Resources office in Portland, Oregon. From these records, 54 erratic locations were documented. Allison (1935) published a comprehensive study of Willamette Valley glacial erratics. Allison's original records are not available, but 42 locations of glacial erratics were located to the quarter- or half-section in his 1935 publication. These 42 locations were digitized using the elevation and Public Land Survey information published by Allison (1935). In addition to these glacial erratics, 249 additional locations were digitized from figure 1 of the same publication. The locations of these 249 glacial erratics are poorly constrained and are symbolized by an open triangle on our maps. Field sheets and notes from mapping completed by Jim Bela (Bela, 1981) in the late 70's and early 80's in the west-central Willamette Valley provided the locations of 16 erratics. Several dozen additional locations were collected from various other scientists. John Eliot Allen (1986) describes the location of 5 erratics. Our own observations and communications with scientists, landowners, and other sources account for another 33 erratic locations. As of June 2003, the database contains records of 400 glacial erratics and their locations; however, approximately 28 of these locations are thought to be duplicates.

Flood features in the Portland basin and Willamette Valley

In addition to leaving the ice-rafted erratics, the Missoula Floods left many other marks on the landscape of the Portland basin and Willamette Valley. Where flowing through constrictions and gaps within low-elevation divides, the floods eroded the basaltic bedrock, forming rocky and channelized scabland, such as the rock-bound depressions now occupied by Lake Oswego and Lacamas Lake. Downstream of constrictions, slowing water dropped its load of bouldery gravel and sand, leaving coarse-grained "deltas" or bars, locally several tens of meters thick, many of which have been fluted by later floods. In backwater areas, each flood dropped part of its suspended load of sand, silt, and clay, leaving up to 40 layers of flood "rhythmites" (Glenn, 1965). These basin-scale features are difficult to discern on the ground, but are clearly expressed in the accompanying shaded relief physiographic map. The most notable features are labeled on the map according to the numbers below:

Figure 4. Southwest-dipping sand and gravel foreset beds exposed in the Portland "delta." Photographed October 4, 1929 by A.M Piper (negative #200).

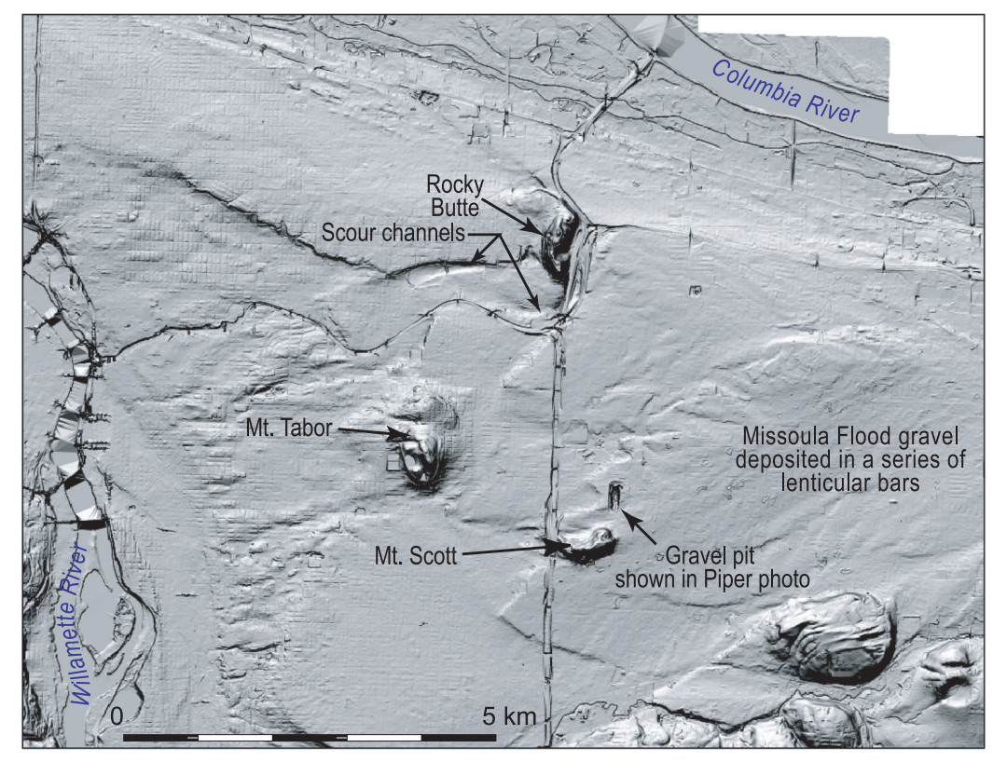


Figure 5. Two-meter resolution digital elevation model and shaded relief map of the Portland delta developed using 2002 photogrammetry. Elevation data courtesy of Metro Regional Services, Portland, Oregon. (shaded relief image prepared by Tana L. Haluska)

PORTLAND DELTA - flood water emerging from the Columbia River Gorge at velocities greater than 30 meters per second slowed as it spread out over the Portland basin and encountered backwater from flow accumulating behind Kalama Gap. As the flow slowed, it began to drop its load of boulders, gravel, and sand entrained from the gorge upstream, forming large "bars" or "deltas" on both sides of the Columbia River. These bars are composed of giant west-dipping foresets (fig. 4). At the eastern end of the delta, immense boulders were deposited-many with diameters exceeding 3 meters. To the west, downstream, the caliber of sediment diminishes to cobbles and finer. Prominent channels on these bars, such as those surrounding Rocky Butte, were formed as flow was steered around small volcanoes and other bedrock protrusions (fig. 5). Smaller delta bars formed downstream of small constrictions in the backflooded Willamette Valley, such as the Durham Delta downstream of the Lake Oswego, and south of the Tonquin Scablands and Oregon City Gap, where water poured into the central Willamette Valley.

TONQUIN SCABLANDS - water rushing southward out of the Tualatin Basin into the Northern Willamette Valley scoured a 3.2 km wide, 8 km long region of channels into underlying Columbia River Basalt and deposited sand and gravel bars on top of the basalt bedrock.

WOODBURN PHYSIOGRAPHIC HIGH - prominent lens-shaped feature, downstream of the Tonquin Scablands and Oregon City Gap, stretching from Wilsonville to Kaiser. This feature is bound on the east by the Labish Channel and Pudding River, bound on the west by the Willamette River, and may be a geologic structure accentuated by the deposition of flood sediments as the velocity of floodwaters decreased after flowing through the Rock Creek and Oregon City Gaps. Current structures indicate that this area was surrounded by a giant clockwise gyre encompassing the entire central Willamette Valley. A series of subtle transverse features, possibly sand and gravel bars, are present at the northern end of the physiographic high.

CHEHALEM CHANNEL - Overflow from the Tualatin Basin flowed up the Tualatin River drainage to the Coast Range, where it flowed southward across a low divide into the northern Willamette basin.

FLOOD RHYTHMITES - Backflooding water flowing into the Willamette Valley was highly charged with fine sand, silt, and clay eroded from the soils and loessal deposits in the Channeled Scabland of eastern Washington. In areas of low velocity, such as the Tualatin Valley and the southern and central Willamette Valley, each flood deposited a layer of this sediment, locally leaving a layer-cake stratigraphy of as many as 40 rhythmically bedded flood deposits with an aggregate thickness of more than 35 meters (Glenn, 1965; Waitt, 1980, 1985). The number of beds and their thickness diminishes with elevation above sea level, and these flood beds cannot generally be distinguished from other surficial deposits above an elevation of 90 meters (300 ft) (figs. 6, 7). This thick accumulation of flood deposits raised much of the valley bottom above the Willamette River floodplain and is the source of both the soils and topography that made the Willamette Valley so attractive to retirees of the Hudsons Bay Company and emigrants forging the Oregon Trail in the nineteenth century.

Maps in this report

The two accompanying maps illustrate the relationship between the inventoried glacial erratics, known levels of floodwater inundation, and the distribution of fine and coarse-grained Missoula Flood deposits. Panel 1 shows the locations of glacial erratics inventoried in our database and flood depth during maximum inundation. The distribution of erratics in our database is consistent with a maximum flood inundation of about 122 meters (400 ft) above sea level for most of the Willamette Valley--an elevation cited as the maximum flood level by many workers (e.g. Allison, 1935, 1978; Glenn, 1956). Locally, especially in the eastern part of the Portland basin, the maximum flood stage may have been higher-perhaps as high as 150 m (500 ft), judging from the scour hole downstream of the 150 m saddle at Rocky Butte (fig. 5). For the purposes of this map, maximum flood inundation is everywhere referenced to 122 m (400 ft).

The distribution and number of flood beds in the rhythmites indicate how many floods achieved certain stages in the backflooded Willamette Valley. At the River Bend section (fig. 6), Glenn (1965) counted 40 flood beds, indicating that at least that many floods inundated the base of section at 35 m (115 ft) above sea level. About 20 separate floods left deposits above the base of the Sidney section at 54 m (177 ft) above sea level, and about 10 flood beds can be counted at the section at Irish Bend at 80 m (260 ft) above sea level (fig. 7) (O'Connor and others, 2001). These levels are also shown on Panel 1.

Figure 6. Missoula Flood rhythmites exposed near the River Bend section of the Willamette River. (Photo by Jim O'Connor)

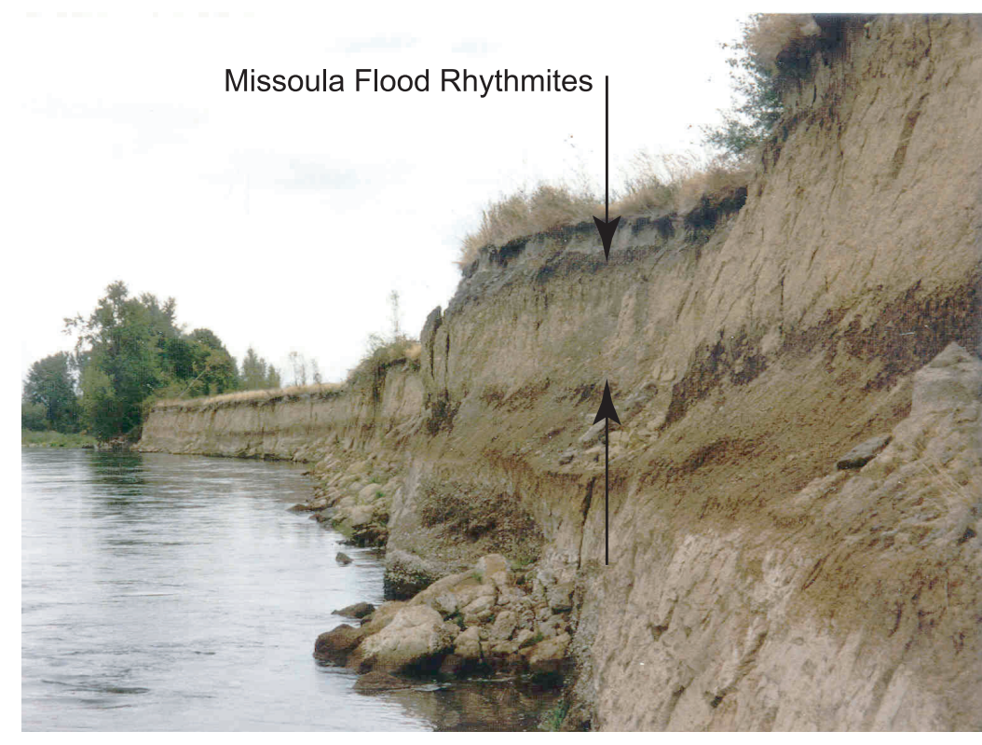


Figure 7. Exposure at Irish Bend, where approximately 4 m of Missoula flood beds overlie older Willamette River deposits and capping soil. 10 m section capped by Holocene overbank deposits and modern soil. (Photo by Marshall Gannett)

The second panel shows the distribution of Missoula Flood deposits mapped in the Willamette Valley and Portland basin, as portrayed by Trimble (1963), Gannett and Caldwell (1998), and O'Connor and others (2001). The coarse facies represents deposits dominated by gravel. The fine facies is primarily sand, silt, and clay. Except for constrictions where there were high velocities, Missoula flood deposits probably mantled most of the landscape below 122 m (400 ft), but typically have mappable thicknesses (>1-2 m) only below 100-120 m (330-400 ft). The abrupt western boundary of some of the flood silt units represents the westernmost limit of mapping. In the Portland basin and northern Willamette Valley, flood deposits are much thicker, locally exceeding 35 m. Flood deposits have been removed or buried by late Pleistocene and Holocene stream activity in some areas below 100 m (330 ft). In other areas, river avulsions have left isolated patches of flood deposits.

Acknowledgements

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References

Allen, J.E., Burns, M., and Sargent, S.C., 1986, Cataclysms on the Columbia: Portland, Oregon, Timber Press, 211 p.

Allison, I.S., 1935, Glacial erratics in Willamette Valley: Geological Society of America Bulletin, v. 46, p. 675-722.

Allison, I.S., 1978, Late Pleistocene sediments and floods in the Willamette Valley: The Ore Bin, v. 40, p. 177-191 and 192-202.

Atwater, B.F., 1986, Pleistocene glacial-lake deposits of the Sanpoil River valley, northeastern Washington: U.S. Geological Survey Bulletin 1661, 39 p.

Baker, V.R., 1973, Paleohydrology and sedimentology of Lake Missoula flooding in eastern Washington: Geological Society of America Special Paper 144, 79 p.

Bela, J.L., 1981, Geology of the Rickreall, Salem West, Monmouth, and Sidney 7.5-minute quadrangles—Marion, Polk, and Linn Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-18, scale 1:24,000.

Benito, G., and O'Connor, J.E., 2003, Number and size of last-glacial Missoula floods in the Columbia River valley between the Pasco Basin, Washington, and Portland, Oregon: Geological Society of America Bulletin, v. 115, p. 624-638.

Bretz, J H., 1925, The Spokane flood beyond the Channeled Scablands: Journal of Geology, v. 33, p. 97-115 and 236-259.

Bretz, J H., 1969, The Lake Missoula Floods and the Channeled Scabland: Journal of Geology, v. 77, p. 505-543.

Condon, T., 1902, The two islands: The J.K.Gill Co., Portland, OR, 211 p.

Diller, J.S., 1895, A geological reconnaissance in northwestern Oregon: U.S. Geological Survey 17th Annual Report, Part I.

Gannett, M.W., and Caldwell, R.C., 1998, Geologic framework of the Willamette lowland aquifer system, Oregon and Washington: U.S. Geological Survey Professional Paper 1424-A, 32 p.

Glenn, J.L., 1965, Late Quaternary sedimentation and geological history of the north Willamette Valley, Oregon: Corvallis, Oregon State University, Ph.D. dissertation, 231 p.

O'Connor, J.E., Sarna-Wojcicki, A., Wozniak, K.C., Polette, D.J., and Fleck, R.J., 2001, Origin, extent, and thickness of Quaternary geologic units in the Willamette Valley, Oregon: U.S. Geological Survey Professional Paper 1620, 52 p.

Pugh, R.N., 1986, Origin of the Willamette meteorite: An alternate hypothesis: Oregon Geology, v. 48, p. 79-80, 85.

Trimble, D.E., 1963, Geology of Portland, Oregon, and adjacent areas: U.S. Geological Survey Bulletin 1119, 119 p.

Waitt, R.B., 1985, Case for periodic, colossal jökulhlaups from Pleistocene glacial Lake Missoula: Geological Society of America Bulletin, v. 96, p. 1271-1286.

MAPS SHOWING INUNDATION DEPTHS, ICE-RAFTED ERRATICS, AND SEDIMENTARY FACIES OF LATE PLEISTOCENE MISSOULA FLOODS IN THE WILLAMETTE VALLEY, OREGON

J. M. Minervini, J. E. O'Connor, and R.E. Wells
2003

Universal Transverse Mercator Projection,
zone 10, 3x vertical exaggeration
compiled from 7.5 minute10-meter DEMs
(available on-line with this report)