Geology and Geomorphology of the Lower Deschutes River Canyon, Oregon

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INTRODUCTION

This field guide is designed for geologists floating the approximately 80 kilometers (50 miles) of the Deschutes River from the Pelton–Round Butte Dam Complex west of Madras to Maupin, Oregon. The first section of the guide is a geologic timeline tracing the formation of the units that compose the canyon walls and the incision of the present canyon. The second section discusses the hydrology, morphology, and formation of the present river channel. The third section is a river log, describing sights and stops for a 3-day floating field excursion.

GEOLOGIC HISTORY OF THE DESCHUTES BASIN

The northward-flowing Deschutes River joins the Columbia River approximately 160 km east of Portland, Oregon, draining a 26,900 km^2 basin that is bounded to the east by the Ochoco Mountains, to the west by the Cascade Range, and to the south by the Klamath and Great Basin Divides (Fig. 1). The basin is formed in sedimentary, igneous, and metamorphic rocks ranging from 250 million to 1.3 thousand years old, but most rocks are Tertiary and Quaternary lavas or other eruptive materials emplaced during the past 65 million years (Fig. 2). Along the route that we will be floating, the present canyon and river course reflect a 20 million year struggle among volcanic, tectonic, and fluvial processes. Since incision of the canyon of the Deschutes River during the Pliocene, lava dams, landslide dams, lahars, and exceptional floods have pinned the river between armored boundaries that were resistant even to the greatest floods of historical times. The cumulative result of the geology, climate, hydrology, and catastrophic past of the drainage basin is a river of remarkably uniform flow in an unusually stable channel.

Field Guide to Geologic Processes in Cascadia: Oregon Department of Geology and Mineral Industries Special Paper 36, 2002.

Clarno and John Day Volcanism: 54–22 Million Years Ago

The central Deschutes Basin and Ochoco Mountains are underlain by volcanic, volcaniclastic, and sedimentary rocks of the Eocene Clarno Formation and the latest Eocene to early Miocene John Day Formation. These rocks formed 54 to 22 million years ago during a stage of subduction-zone volcanism predating and early in formation of the Cascade Range, and consist of lavas of various compositions, volcanic-ash flows, tuffaceous sedimentary rocks, and clay-rich paleosols. Erodible tuffaceous units and cliff-forming basalt of the John Day Formation also underlie younger Tertiary and Quaternary rocks in the valley of the lower Deschutes River (Fig. 2). Where the river has cut through these tuffs, canyon walls are particularly susceptible to landsliding, and all of the large landslide complexes in the lower Deschutes Basin are within these units.

Columbia River Flood Basalt: 17–14.5 Million Years Ago

Between 17 and 14.5 million years ago, flows of the Columbia River Basalt Group (CRBG) buried the northern and northeastern portions of the lower Deschutes River Basin with lava up to 600 meters deep. These lavas, which cover a total of 165,000 km^2, issued from numerous vents in eastern Washington, western Idaho, and eastern Oregon. Contemporaneous

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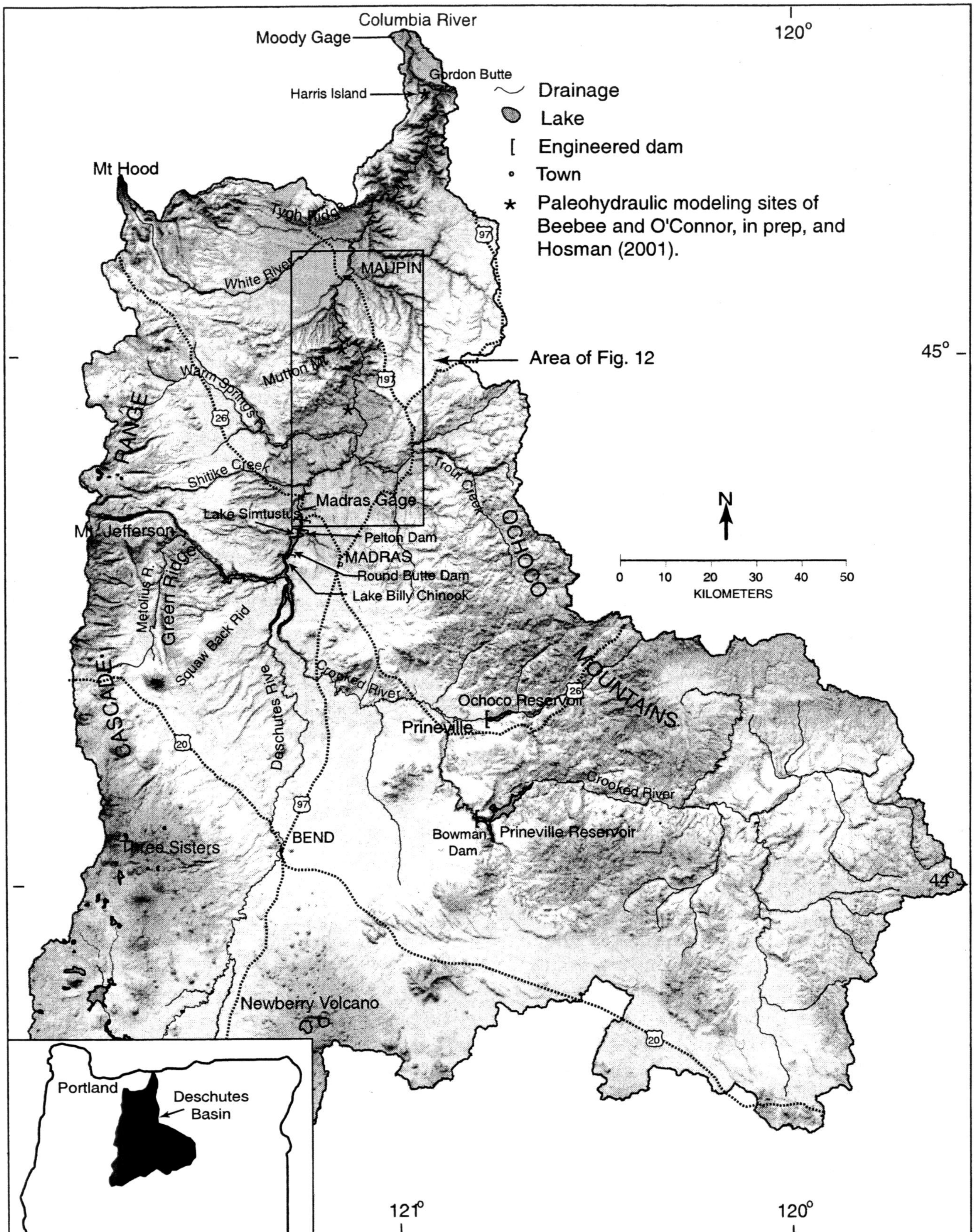

Figure 1. Drainage basin map of the Deschutes River.

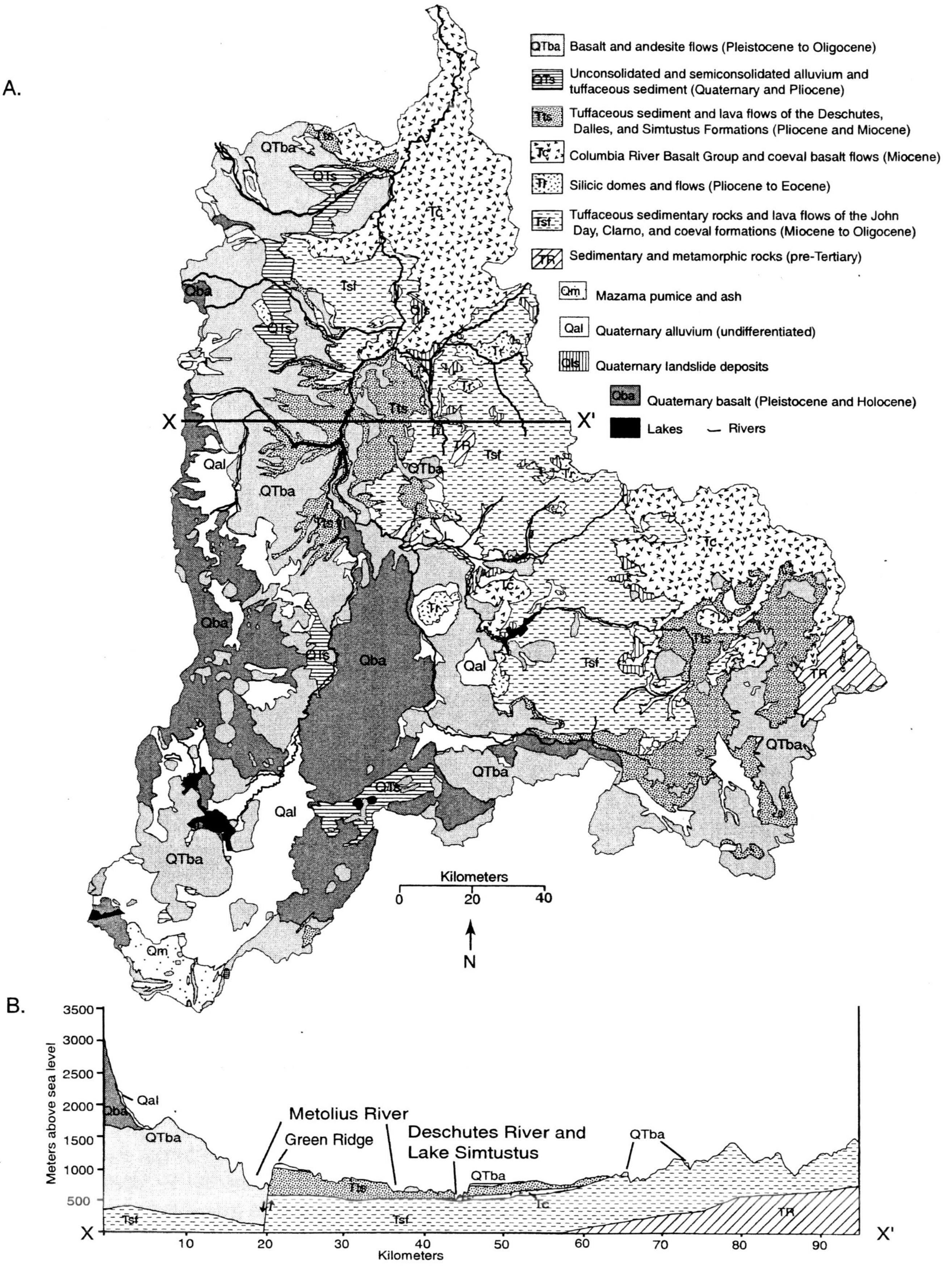

Figure 2. A. Geology of the Deschutes Basin generalized from Walker and McLeod (1991). B. Geologic cross section along line X to X' after Smith (1986).

Prineville Basalt, distinguished by elevated P_2O_5 and Ba, flowed from vents near the Bowman Dam site on the Crooked River and mingled with CRBG flows traveling south from the Columbia River (Hooper and others, 1993). The distribution of CRBG and contemporaneous basalts suggests that the geometry of the Deschutes Basin as a northward drainage between the Ochoco Mountains and the ancestral Cascade Range had been established by 17 million years ago (Smith, 1986).

A Very Different Deschutes River: 12–4 Million Years Ago

Following the emplacement of the Columbia River Basalt Group, volcanic debris from Cascade Range volcanism began to fill the Deschutes Basin between Bend and Trout Creek (Smith, 1986). These deposits, which constitute the Deschutes Formation, consist of ignimbrites, lahar deposits, ash-flow and air-fall tuffs, fluvial sediments, and basalt flows emplaced between 12 and 4 million years ago. Similar sedimentary units interbedded with volcanics were deposited south of Tygh Ridge and along the Columbia River. These are known as the Dalles Formation, which is generally analogous to the Deschutes Formation. Most of the silicic volcanic rocks in the Deschutes Formation were erupted from the ancestral Cascade volcanoes, with minor input from vents to the east, while mafic vents within the Deschutes Basin supplied basaltic lava (Smith, 1986; Hayman, 1983).

Gravel of the ancestral Deschutes River within the Deschutes Formation indicates that between 7.4 and 4 million years ago, the river was situated similarly to the modern Deschutes River, but instead of flowing through a narrow canyon, it spread out across a broad plain several hundred meters higher than its present altitude, continually aggrading and retrenching in response to influxes of volcanic material from the west (Smith, 1986). The distribution and thickness of fluvial and volcaniclastic deposits in the Deschutes Formation suggest that the ancestral Deschutes River switched from a mostly aggrading channel to a mostly degrading channel near the present position of Lake Simtustus, due to a northward decrease in volcanic sediment supply from the ancient Cascades and to uplift in the northern part of the basin (Hayman, 1983; Smith, 1982).

Sinking Volcanoes and Local Lava: 6–4 Million Years Ago

The Deschutes Formation was capped by basalt flows from vents in the central Deschutes Basin near Round Butte Dam and Squaw Back Ridge between 6 and 4 million years ago. The lavas cover broad upland surfaces, indicating that the Deschutes River and its tributaries had not yet cut deep canyons. At the same time, westward extension caused the Pliocene Cascade volcanic platform to sink several hundred meters. Green Ridge is a local bounding scarp of the High Cascade Graben (Fig. 2B). The eruptive style of the Cascade Range volcanoes shifted from silicic to generally less explosive mafic volcanism (Smith and Priest, 1983), and material shed from them no longer had a direct route to the Deschutes Basin. The Deschutes River began to cut back down through layers of lava and sediment around 4 million years ago, incising to near-present altitudes near Round Butte by about 1.2 million years ago (Smith, 1986).

Lava Dams at Both Ends: 1.6–0.7 Million Years Ago

Between 1.2 and 0.7 million years ago, basaltic lava from Newberry Volcano to the south repeatedly flowed into the Crooked River Gorge and partially filled the Crooked, Deschutes, and Metolius Canyons at the present location of Lake Billy Chinook (Sherrod and others, in press), damming the river and forcing it to cut a new channel around the flow margins. The river was similarly dammed during the Quaternary by an undated basalt flow from Gordon Butte that entered the canyon about 8 km upstream from the Columbia River confluence (Newcomb, 1969).

Bend–Tumalo Eruptions: 400,000 Years Ago

Huge volumes of silicic volcanic rocks erupted around 400,000 years ago from vents in the Bend–Tumalo area (Hill and Taylor, 1989). Thick accumulations of the Bend Pumice remain in the upper Deschutes Basin, and several terrace deposits preserved in the lower Deschutes Canyon contain the pumice. Pyroclastic flow deposits on a gravel terrace near Shitike Creek indicate that the river was locally clogged with sediment during or shortly after these eruptions (Hayman, 1983). The Bend Pumice has been found in terraces as far downstream as

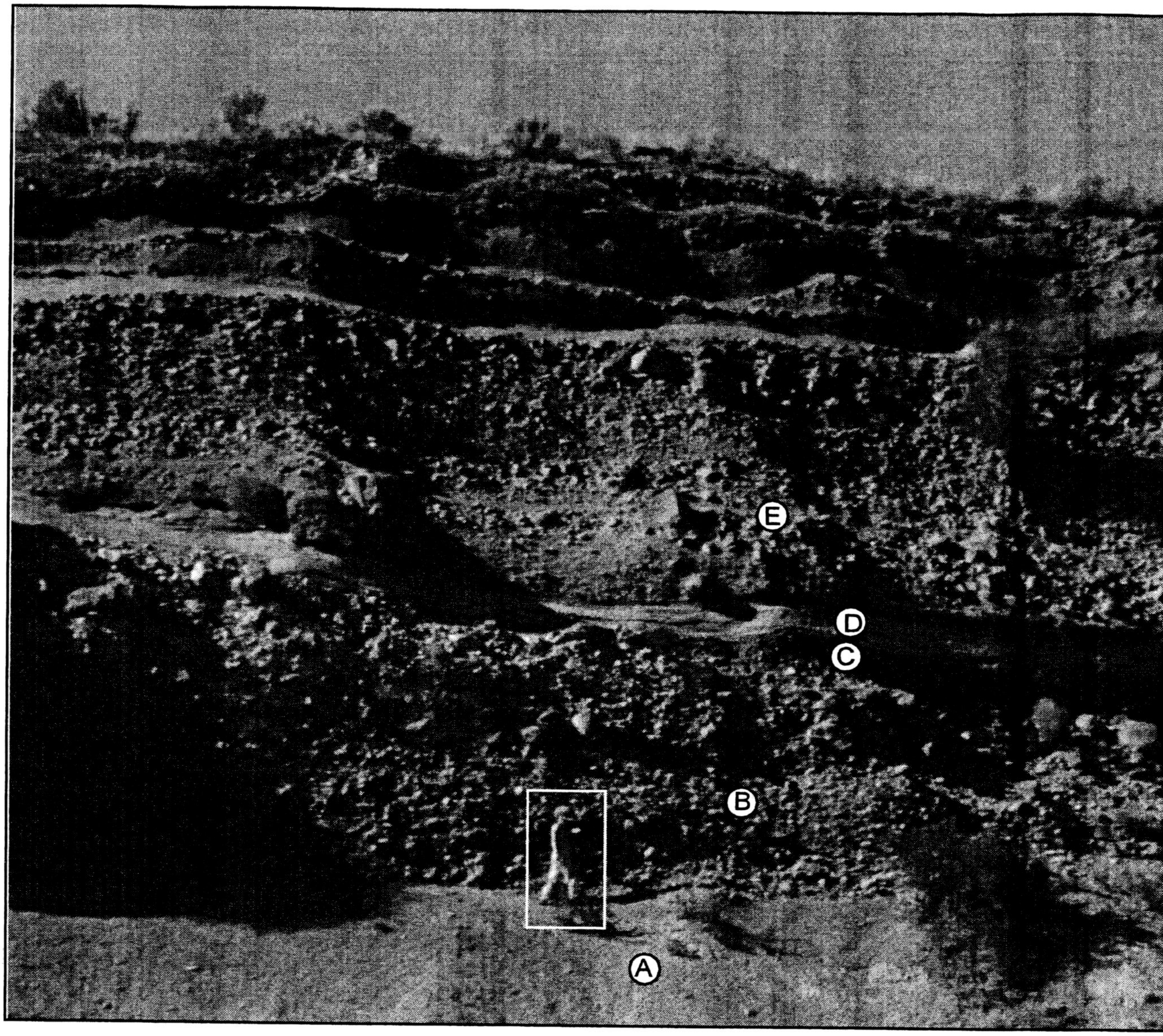

Figure 3. South Junction Terrace, River Mile 83.5 (Stop 3). A. Tilted strata of the John Day Formation. B. Fluvial gravel. C. Fluvial sand. D. Ashy lahar. E. Gravelly lahar. Unit E contains pumice clasts from a roughly 100,000 year old Mt Jefferson eruption (O'Connor and others, in press). The person is 1.68 m tall.

River Mile (RM) 31, suggesting that before this eruptive cycle, the river may have aggraded throughout much of its length.

Mt Jefferson Lahar: 100,000 Years Ago

Along the lower 50 kilometers of the river, gravelly lahar deposits approximately 15 meters above the current river level contain pumice from a 100 ka eruption of Mt Jefferson. This lahar traveled at least 200 kilometers from its source, apparently a record for the Cascade Range (J.E. O'Connor and A.M. Sarna-Wojcicki, unpub data, 2000). Pumice and ash-rich lahar deposits from the Mt Jefferson eruption are also interbedded in fluvial gravel 50 meters above river level near the Warm Springs River confluence (Fig. 3).

Pleistocene Landslide Dams and Outburst Floods: 40,000–10,000 Years Ago

Although undoubtedly impressive at the time, volcanic eruptions during the Quaternary have left far less of a mark on the modern channel of the Deschutes River than have landslides from the canyon walls. Uplift of the Mutton Mountains, along with changes in base

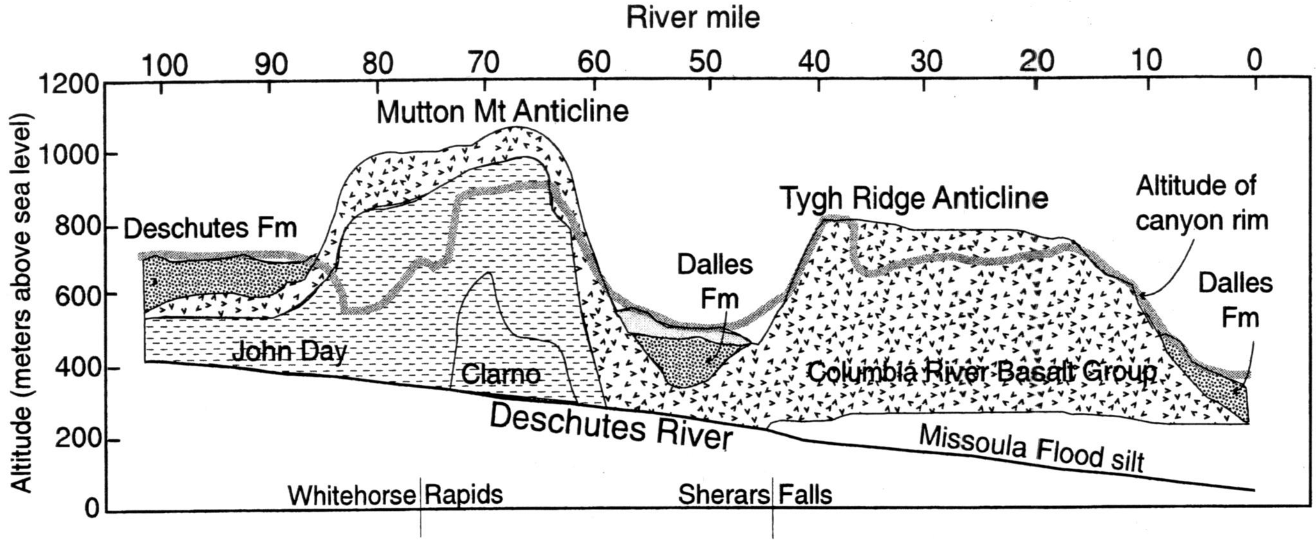

Figure 4. Longitudinal profile of the lower Deschutes River showing the exposed geology of the canyon. The gray line represents the altitude of the canyon walls superimposed on the total relief of the surrounding visible geologic formations and structures. Patterns follow Figure 2.

level and sediment delivery, have caused the Deschutes River to cut a deep canyon through alternating resistant lava flows and soft volcaniclastic sediment (Fig. 4). Between the Pelton–Round Butte Dam Complex and North Junction (RM 70), the river cuts through the soft sediment of the John Day Formation, capped by lava of the John Day Formation, the Columbia River Basalt Group, and the Deschutes Formation. This sequence of lithologies is particularly susceptible to slope failure, and mass-movement deposits ranging from single slump blocks to hummocky landscapes covering 50 square kilometers dominate the valley walls along this segment of the river. Many of these blocks likely have been slowly slumping throughout incision of the river, but several landslides were rapid enough to dam it during the Pleistocene. These include Whitehorse Rapids Landslide (The Pot) that created Whitehorse Rapids (RM 79-75), the large debris flow near Dant (RM 64), and the landslides that delivered boulders to Wapinitia and Boxcar Rapids at RM 55-53 (Fig. 5). Trout Creek Rapids may also be the remnant of a landslide dam or breach deposit. Few dates constrain these mass movements and resulting floods, but they all seem to have occurred during the Pleistocene, based on the amount of surface erosion and weathering of boulders in the deposits. Whitehorse Rapids Landslide seems to be the youngest large mass movement, and its persistent influence on the channel is difficult for boaters to ignore. Whitehorse Rapids, which drops 12 meters over less than 1 kilometer, is the remains of the landslide dam, and high bouldery deposits directly downstream from the rapids were deposited when the dam failed catastrophically (Figs. 6, 7). The presence of airfall tephra from the 7.6 ka eruption of Mt Mazama (Zdanowicz and others, 1999) in a closed depression in the landslide hummocks suggest that the Whitehorse Rapids Landslide occurred prior to that time. Radiocarbon dates from flood deposits downstream from Whitehorse Rapids indicate that the landslide dam breached catastrophically at least once between about 40 ka and 3.8 ka (O'Connor, Curran, and others, in press).

Missoula Floods: 15,000–12,000 Years Ago

When ice dams impounding Glacial Lake Missoula failed repeatedly in the Pleistocene, floodwater traveled down the Columbia River and backed up in tributaries to an altitude of approximately 300 meters above sea level in the vicinity of the Deschutes River. Slackwater silt and ice-rafted boulders were deposited on the banks of the Deschutes River as far south as

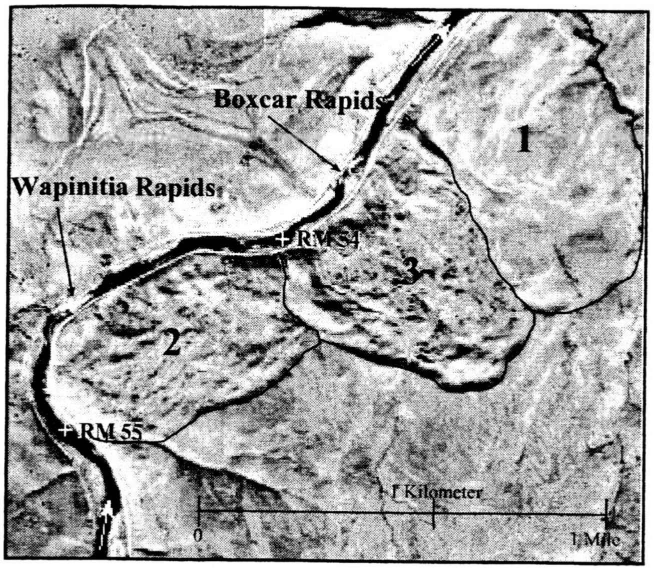

Figure 5. Air photo of overlapping landslides numbered 1–3 (oldest to youngest) at River Mile 55–53, and the rapids they created.

Maupin (Orr and others, 1992). The effects of the Missoula Floods are not evident upstream from Maupin, but its tan silt up to several meters thick mantles the banks of the Deschutes River downstream from about RM 50.

Outhouse Flood: 4100–2800 Years Ago

Bouldery cobble bars, massive sand deposits, and stripped bedrock surfaces 5 to 19 meters above summer low flow stages along the lower Deschutes River were left by at least one exceptional Holocene flood that was substantially larger than any historic flow (Figs. 8, 9). The Outhouse Flood, named for Bureau of Land Management toilet facilities built on many of its bouldery deposits, occurred during the middle Holocene, between 4.1 and 2.8 ka (Beebee and O'Connor, in press). Because of the disparity in flow magnitude between the largest historic flows and the discharge indicated by the high and coarse-grained Outhouse Flood deposits, we originally interpreted the Outhouse Flood to be the result of some sort of dam breach within the basin, similar to but more recent than that caused by th breaching of the Whitehorse Rapids Landslide. However, no obvious middle Holocene breach site has been located, and step-backwater modeling of three reaches at River Miles 82, 65, and 11 indicates that discharge increased substantially downstream in a manner similar to historical storm floods (Fig. 10). Hence our current interpretation of these features is that they were formed by an exceptional meteorological flood with a discharge 2–3 times as great as any flood of record.

Old Maid Lahar: Approx AD 1800

Mt Hood's Old Maid eruptive cycle about AD 1800 produced at least one lahar that entered the Deschutes River via the White River. Its volume was meager compared to lahars from the Bend–Tumalo and Mt Jefferson eruptions, but remnant gray pebbly sands lie near the White River confluence at RM 47, well above the stages of floods during the past 200 years.

Historical Flood: AD 1861

According to written accounts and geomorphic evidence, the rain-on-snow flood in December 1861 was the largest historical flood in the lower Deschutes Basin (Anonymous, 1861). Studies of the Crooked River suggest that the 1861 flood was the biggest flood in that drainage during the entire Holocene (Levish and Ostenaa, 1996). The stratigraphic position of deposits from the 1861 flood at the lower Deschutes River also shows that it was larger than recent floods in 1964 and 1996 (Fig. 8), which were regulated upstream by dams.

Ochoco Dam: AD 1920

The engineered Ochoco Dam near Prineville closed in 1920, providing flow regulation in the Crooked River part of the Deschutes Drainage Basin.

The Dalles Dam: AD 1956

The Dalles Dam on the Columbia River closed in 1956, flooding the mouth of the Deschutes River and Celilo Falls on the Columbia River.

Bowman Dam: AD 1960

Bowman Dam on the Crooked River closed in 1960, providing flood control and water storage in the Crooked River Basin.

Pelton–Round Butte Dam Complex and Flood: AD 1964

The Pelton-Round Butte Dam Complex was completed in 1964, creating Lake Billy Chinook. In December 1964, a rain-on-snow event produced record floods on the Crooked

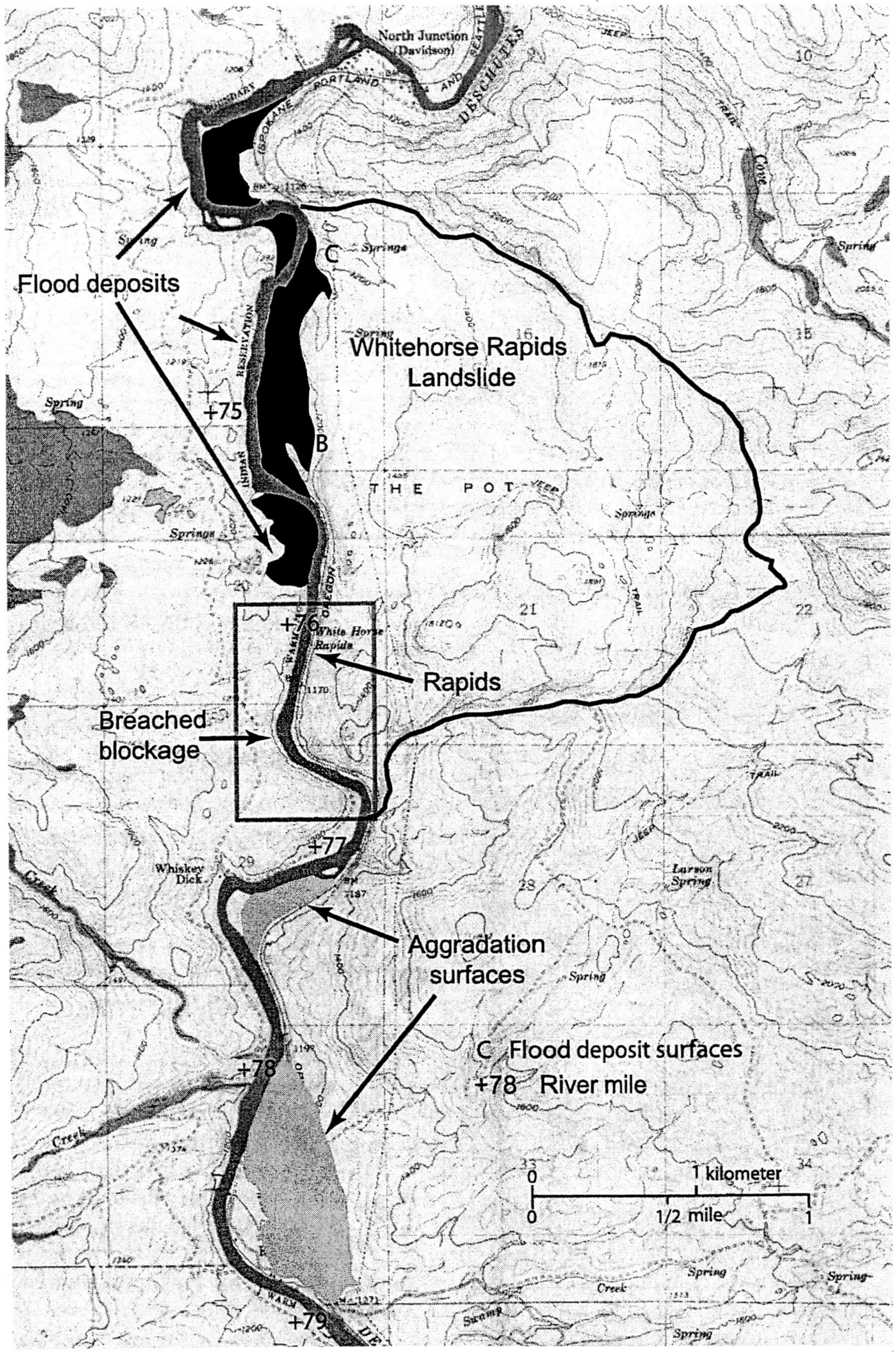

Figure 6. Geomorphic features related to the dam produced by the Whitehorse Rapids Landslide and the area of its outburst flood deposits plotted on the U.S. Geological Survey Kaskela 7.5-Minute Quadrangle.

and Deschutes Rivers. Because Lake Billy Chinook was not yet full, the Pelton–Round Butte Dam Complex provided some flood control. Presently, the dam is operated for hydropower and recreation but does not provide flood control because it is kept full.

Historical Flood: AD 1996

The February 1996 flood was caused by a rain-on-snow event similar to the one in 1964. Although this flood was regulated by the Ochoco and Bowman Dams, Lake Billy Chinook was already full, and the flood wave passed through the Pelton–Round Butte Dam Complex without attenuation. The 1996 and 1964 floods were similar in discharge, and they are calculated to have a recurrence interval of about 100 years in light of both the gaged record and the stratigraphic record of flooding during the past 2000 years (Hosman and others, in press).

QUATERNARY GEOMORPHOLOGY AND HYDROLOGY

Many of the geomorphic studies described in this field guide were conducted in conjunction with Federal Energy Regulatory Commission's relicensing of Portland General Electric's Pelton–Round Butte Dam Complex. The earliest studies were begun in 1995 to determine the specific effects of the dams on the downstream hydrology, channel form, and aquatic habitat. The unexpected conclusion, first described in a pair of Oregon State University theses, was that the dam had little apparent influence on physical aspects of the river downstream from Lake Billy Chinook (McClure, 1998; Fassnacht, 1998). These results differ from studies of other regulated rivers that showed significant changes in channel and floodplain sedimentation, and consequently aquatic habitat, in the decades following impoundment (Andrews and Nankervis, 1995). The absence of such effects on the Deschutes River inspired follow-up studies aimed at providing overall understanding of important geomorphic processes controlling valley-bottom and channel conditions (Curran and O'Connor, in prss; Grant and others, 1999; O'Connor, Grant, and Haluska, in press). The conclusion of these latter studies is that the interruption of sediment and water flux by the dam complex has been minor compared to natural flow regulation and sedi-

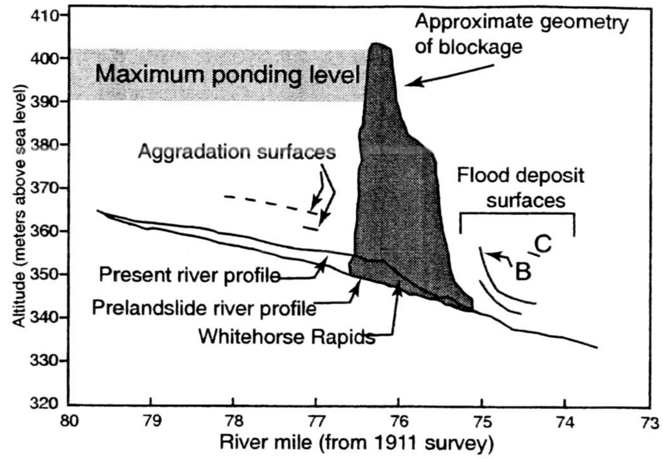

Figure. 7. Diagram of the breach site of the Whitehorse Rapids blockage showing the probable former river profile and the profile after the blockage. Surfaces B and C are labeled on Figure 6.

ment trapping upstream of the dam. The river's steady discharge has been noted since the very first studies of the Deschutes River and is one of its most remarkable aspects. For example, Russell (1905) wrote

> The Deschutes is of especial interest to geographers, as it exhibits certain peculiarities not commonly met with. Although flowing from high mountains on which precipitation varies conspicuously with seasonal changes and where snow melts rapidly as the heat of summer increases, its volume, throughout a large section of its course, is practically constant throughout the year.

The young unincised volcanic terrain provides natural flow regulation in the southern and western parts of the drainage basin (Fig. 2). There, precipitation and snowmelt drain into porous aquifers and discharge from voluminous cold springs months to decades later (Manga, 1996). Snowpack, lakes, and a few glaciers in the Cascade Range also store and release seasonal precipitation, further dampening month-to-month variation in discharge. The resulting steady flow of the Deschutes River is striking when compared with flow characteristics of the neighboring John Day and Willamette Rivers (Fig. 11). Peak gaged flows on the Willamette

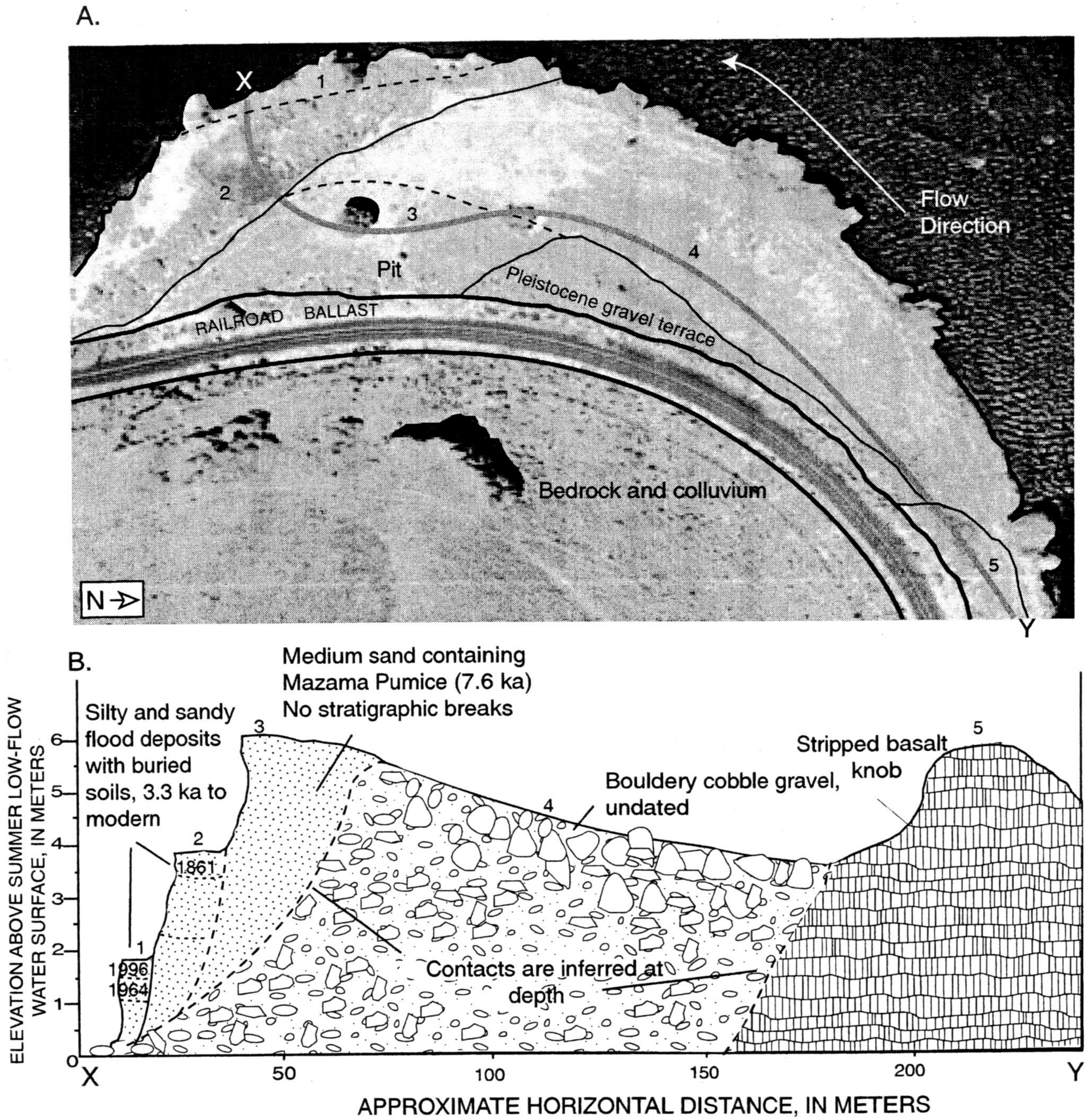

Figure 8. A. Air photo of an Outhouse Flood bar near Dant, River Mile 65 (Stop 7). B. Cross section of the flood bar along line X to Y.

and John Day Rivers were more than 20 times the river's mean flow, whereas peak gaged flow (in Feb 1996) on the Deschutes River was less than 5 times the mean flow.

Fluvial erosion and transport of sediment in the basin is hindered by the lack of integrated surface drainage and high-discharge events in the young volcanic terrain. A 1998 survey of the sediment trapped in the arms of Lake Billy Chinook revealed that the Deschutes and Crooked Rivers had been delivering less bedload over the previous 34 years than any other river of comparable size reported in the world literature (O'Connor and others, in prep). With little incoming sediment to trap and little floodwater to store, the Pelton–Round Butte Dam Complex has not resulted in such downstream impacts as bed coarsening,depth reduc-

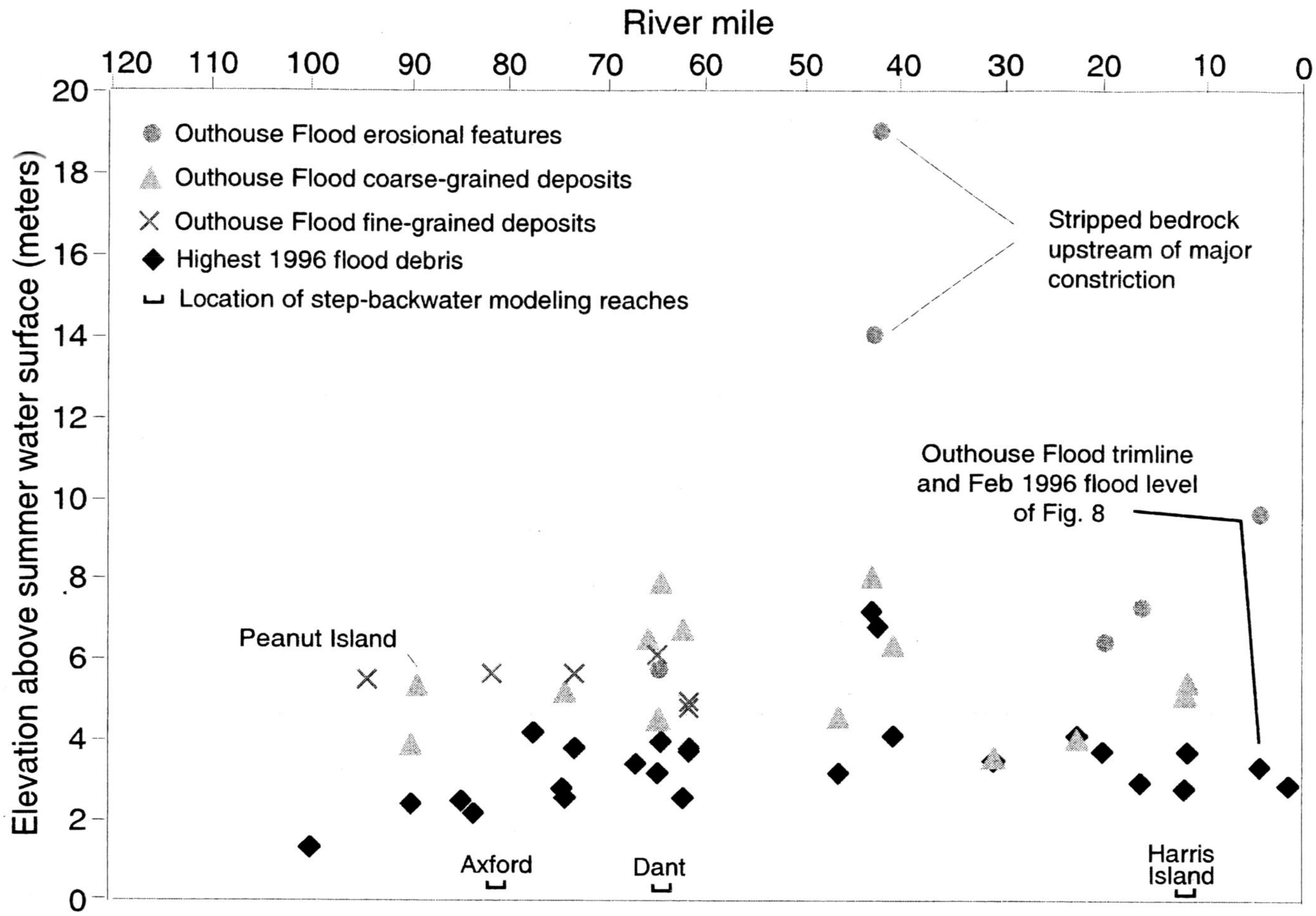

Figure 9. Comparison of the surveyed heights of paleostage evidence from the February 1996 flood and the Outhouse Flood.

tion, or channel narrowing (Fassnacht and others, in prep).

Studies spanning the 1996 flood concluded that this event, which was the largest in 135 years, did not substantially affect the channel form. The resilience of the channel boundaries is a testament to the magnitude of the previous events that shaped them relative to the modern hydrologic regime. Mass movements and high-magnitude paleofloods (such as the Outhouse Flood) transported sediment into the channel that has been immobile for thousands of years. As an indication of how influential these former high-magnitude events have been, 35% of all alluvial surfaces flanking the lower 160 kilometers of the Deschutes River were deposited by the Outhouse Flood alone, and they haven't been reworked for at least 3,000 years. Similarly, 11 of the 23 named rapids on the river are composed of coarse alluvium introduced into the channel by either the Outhouse Flood or by Pleistocene mass movements, and they were not significantly modified by historical floods (Curran and O'Connor, in prep). For the time being, the canyon that was clogged by hot ash and lava, dammed by landslides, and carved out by floods, houses a remarkably stable, subdued, and indeed, ineffective river.

RIVER LOG

Field trip stops are shown on Figure 12. Distances are given in river miles (RM), which are measured from the mouth of the river and interpolated from river miles marked on 7.5-minute U.S. Geological Survey topographic quadrangles. The directions "river right" and "river left" assume you are looking downstream to the north.

Between the Metolius River and North Junction (RM 69), the entire left (west) bank of the Deschutes River is on the Warm Springs Indian Reservation and is accessible by permit

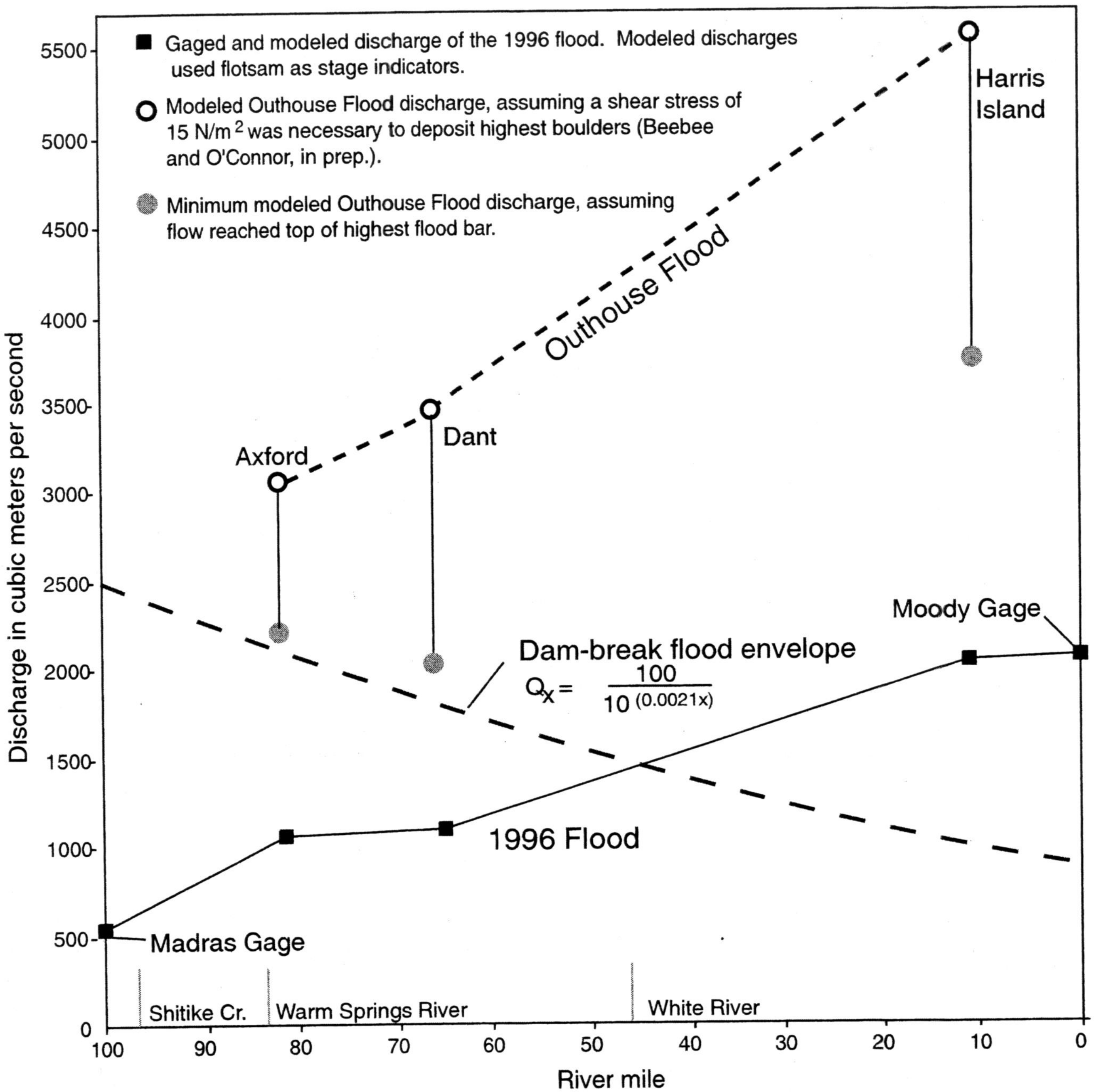

Figure 10. Comparison of modeled discharges of the Outhouse Flood with gaged and modeled discharges of the February 1996 storm flood. Envelope defining the peak discharge attenuation of historical dam-breach floods is from Costa (1988). In this equation, x is the distance downstream from the breach in km, and Qx is percentage of discharge at the breach.

only. Although the majority of riverbanks are public land, some stops involve private property, and permission of the landowners should be obtained prior to entering. As a State Scenic Waterway and a National Wild and Scenic River managed by the Bureau of Land Management, the Deschutes River has certain restrictions for trip size and collecting that should be followed. Most importantly, the Deschutes River is a whitewater river in the area covered by this field guide and should be floated only by experienced whitewater rafters or as part of a professionally guided expedition.

The U.S. Geological Survey 7.5-minute quadrangles that cover the course of the trip are, in downstream order, Madras West, Eagle Butte, Gateway, Kaskela, Dant, Maupin SW, Tygh Valley, and Maupin. Useful geologic maps from

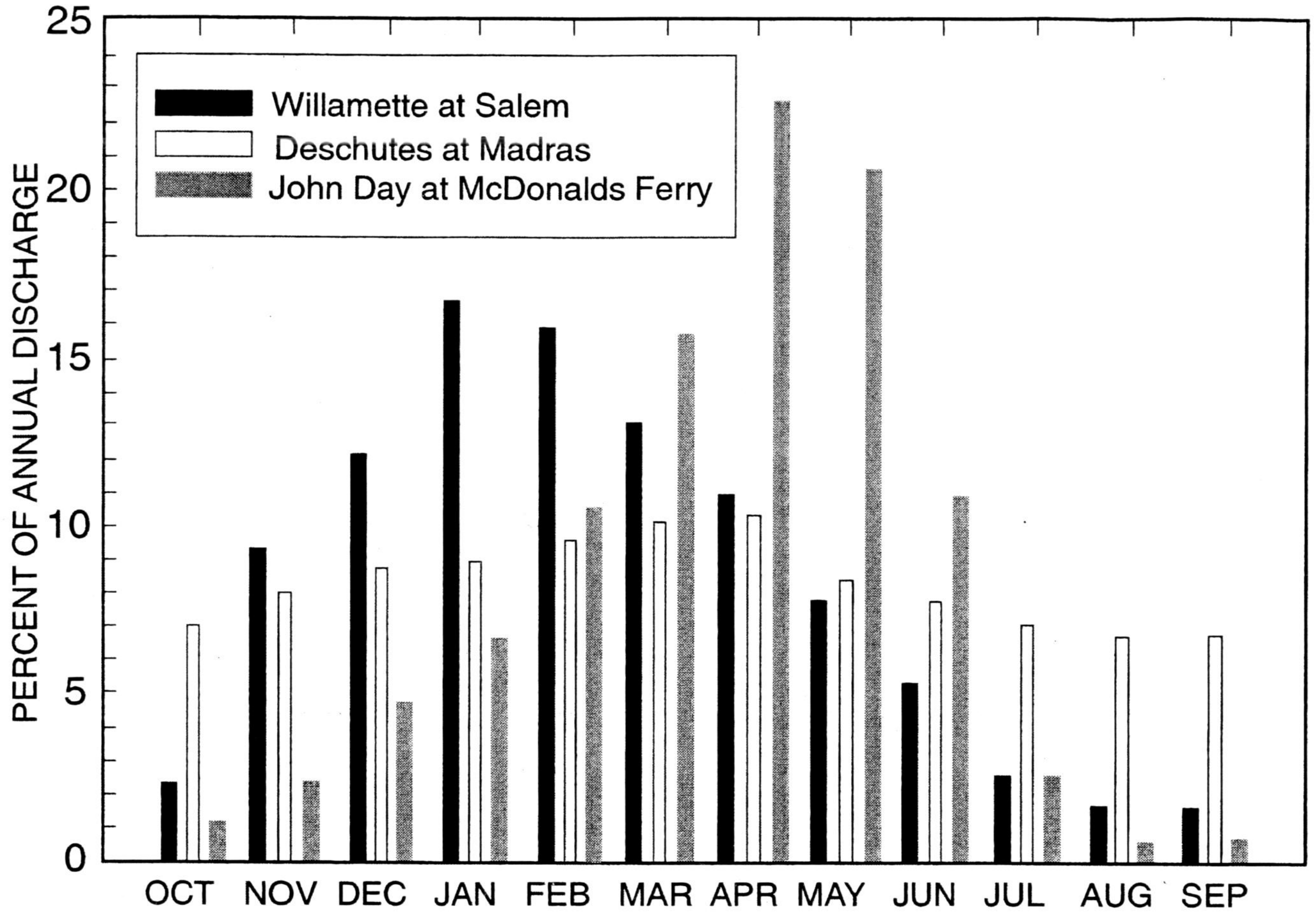

Figure 11. Bar graph showing mean monthly discharge of the Deschutes River, John Day River, and Willamette River.

which we have drawn much of the information presented about the pre-Quaternary geology include Smith (1987, 1:24,000-scale mapping of the Madras West and Madras East Quadrangles), Smith and Hayman (1987, 1:24,000-scale mapping of the Eagle Butte and Gateway Quadrangles), Waters (1968, reconnaissance geologic map of the Madras 15-Minute Quadrangle—covering the Eagle Butte, Gateway, and Kaskela 7.5-Minute Quadrangles along the trip route), and Bela (1982, 1:250,000-scale compilation of The Dalles 1x2-Degree Quadrangle—including the Dant, Tygh Valley, Maupin SW, and Maupin 7.5-Minute Quadrangles along the trip route).

RM 100.1: Reregulation Dam

We will embark just below the Reregulation Dam, which stores flow fluctuations due to power generation at the Round Butte and Pelton Dams upstream, releasing almost natural flows. These three dams are jointly owned and operated by Portland General Electric and the Confederated Tribes of Warm Springs. Pelton Dam (which impounds Lake Simtustus approximately 4 kilometers upstream) and the Reregulation Dam were constructed in the late 1950s, and Round Butte Dam (which impounds Lake Billy Chinook approximately 16 kilometers upstream) was constructed in the early 1960s. Total power generation capacity is 427 megawatts. Note that this property is owned by Portland General Electric and is not open to the public.

RM 100: U.S. Geological Survey gaging station (Deschutes River near Madras). Cross-section geometry extracted from discharge measurements over the period of 1957-1998 shows little change in channel morphology (Fassnacht and others, in prep).

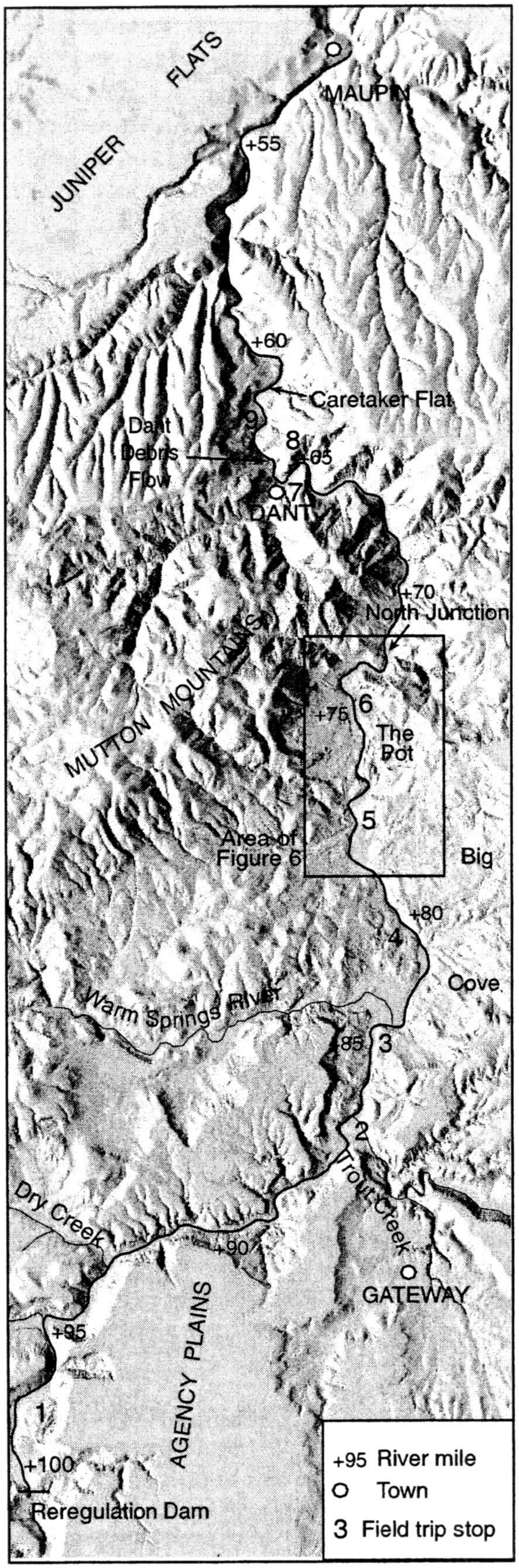

Figure 12. Field trip route with stops and river miles on a U.S. Geological Survey 10-meter digital elevation model (DEM).

RM 99: Quaternary terrace near river level and large slump complex upslope, both on river right.

RM 98: Stop 1. Disney Riffle

This has been the site of both geomorphic and ecologic investigations examining downstream effects of the dams. These studies have revealed surprisingly few effects on channel morphology, bedload transport, or bed texture. No evidence of channel degradation or bed coarsening below the dams has been observed, which we attribute to the unusually steady flow regime, very low rates of sediment supply above the dam, low frequency of bedload transport, and resistant channel boundaries.Evidence for low transport frequency is observed in salmon-generated dunes just downstream from this site along the margin of the right-hand island. These redds have not changed position or amplitude in the 15 years since they were last occupied.

RM 97: Highway 26 crossing. Public boat launch on river right, Shitike Creek confluence on river left. Quaternary terraces on river right contain pyroclastic flows from the Bend–Tumalo eruptions.

RM 95: Mecca Flat and public boat launch on river right. Light-colored layers exposed in erosion gullies on both sides of the river are tuffaceous sedimentary rocks of the John Day Formation. The John Day Formation is overlain by two Prineville basalt flows (middle Miocene), which in turn are overlain by poorly exposed Deschutes Formation and capped by the 5.3 Ma Agency Plains basalt flow.

RM 94: Dry Creek confluence on river left. The small channel circling the island at the tributary mouth is an important spawning area for resident rainbow and steelhead trout.

RM 93.5: Thin sedimentary beds of the Simtustus Formation are exposed between two Prineville basalt flows near the canyon rim on both sides of the river.

RM 90: Talus-covered slump complexes appear on both sides of the river.

RM 89: Peanut (Big) Island is a large boulder bar deposited by the Outhouse Flood in a local channel expansion. This is the most upstream feature confidently attributed to the Outhouse Flood, and it stands 5.3 meters above typical low-flow water level.

RM 88: Stop 2. Gateway Recreation Area

This boulder-studded alluvial surface on river right is interpreted as another Outhouse Flood bar, although local mass movements probably contributed some of the angular boulders. From this point until we enter the Mutton Mountain Anticline at RM 70, the canyon walls retreat into an undulating mass of ancient slump blocks composed of John Day Formation tuff and interbedded lava flows. The slump complex on river right between RM 85 and RM 75 is known as Big Cove. Smaller slump blocks directly downstream from Trout Creek may have impinged on the channel.

RM 87: Trout Creek Rapids. Boulders that make up Trout Creek Rapids were either part of a landslide that encroached on the channel, or outwash from a breached landslide dam.

RM 86: The tracks of the Burlington Northern Santa Fe Railroad descend Trout Creek to near river level and follow the Deschutes River for the remainder of their course to the Columbia. Originally constructed as the Oregon Trunk Line in 1910, this is one of two separate railroad lines that flanked the Deschutes River during the early 20th Century.

RM 83.5: Stop 3. South Junction Campground

Take out at the sandy bar on river right 200 meters downstream from the Warm Springs River confluence, then walk back upstream on the railroad tracks to the terrace exposure in the railroad cut (Fig. 3). Watch for the Burlington Northern Santa Fe coming around the bend. Lahar deposits in this terrace contain pumice from a roughly 100 ka eruption of Mt Jefferson. This terrace may correlate with Jefferson pumice-bearing bearing terraces downstream from RM 35.

Stop 4. Axford Flood Deposits

A sequence of fine-grained flood deposits several meters thick with dates spanning 7,000 years is exposed in a cutbank at the downstream end of the alluvial surface on river left. This site on Warm Springs Reservation property has been used for paleohydraulic modeling of the largest floods of the past several thousand years (Hosman, 2001; Hosman and others, in prep; Beebee and O'Connor, in prep).

RM 79: Kaskela Ranch on river right. This terrace and the surfaces downstream may represent aggradation behind the dam made by the Whitehorse Rapids Landslide (Figs. 6, 7).

RM 78.5: Stop 5. Whiskey Dick

Camp on river right. This gravel terrace, which was extensively quarried for railroad ballast during 1910-1912 railroad construction, is one of a series of terraces upstream from the Whitehorse Rapids Landslide (Fig. 6). None of these terraces has been dated, but we interpret them to be the result of aggradation behind a river blockage formed by the Whitehorse Rapids Landslide.

RM 77: Stop on river right and scout Whitehorse Rapids. Whitehorse Rapids are the largest rapids between Madras and Maupin, and over which the river drops about 12 meters in less than 1 kilometer. These rocky rapids are the remains of a landslide dam that breached catastrophically during the Pleistocene.

RM 76: Stop 6. The Pot

Take out on river right (Fig. 6) and climb up among the hummocks and knobs of The Pot to look at the landslide and breach site. Just downstream from the rapids, boulder bars, levees (on both sides of the river), and scoured divides are evidence that at least one large flood resulted from a breach of the landslide dam. A radiocarbon date on charcoal that accumulated in a small closed depression formed by a flood bar yielded an age of 3,820±240 ^{14}C yr ago, providing a minimum date for the outburst flood.

RM 74.5: Optional Stop

A railroad cut on river right exposes bouldery foresets containing Mt Jefferson pumice and charcoal dated at 38,760±540 ^{14}C yr ago, reinforcing the maximum date on the outburst flooding from the Whitehorse Rapids Landslide dam.

RM 74–73.5: The river curves around an enormous gravel and boulder bar on river right, probably a landslide-dam breach deposit.

RM 73: North Junction. Due to sheer cliffs, land acquisition difficulties, and intervention by the Federal Government, two competing railroad lines laying track on either side of the river joined forces to construct a single line on the east bank between North Junction and South Junction. The east-bank line, originally constructed by the Oregon–Washington Railroad and Navigation Company, was gradually abandoned, and for the rest of the course of the field trip the old railbed serves as a road on river right. Between here and RM 54, this road and much of the right bank is privately owned.

RM 72: The river enters the Mutton Mountains, which are composed of uplifted John Day and Clarno Formations capped by flows of the Columbia River Basalt Group. The John Day and Clarno Formations here are composed of rhyolitic to andesitic lava flows, and they are far more resistant than the soft tuffaceous sedimentary facies upstream. Uplift of the Mutton Mountains has caused the river to incise a deep, narrow, meandering canyon in this reach. Several vacation homes on river right between RM 70 and 57 were damaged during the 1996 flood.

RM 69: Leaving Warm Springs Reservation on river left.

RM 66: Large Outhouse Flood bar on river right.

RM 65: Stop 7. Dant

Camp on river left, across the river from an old railroad tunnel. Several meters of fine-grained flood deposits, capped by 1964 and 1996 flood sands, are exposed in the cutbank at the downstream end of this bar (Fig. 8). A silt line deposited by the 1861 flood is preserved within a higher adjacent sequence, providing a paleostage indicator for estimating discharge. Sand deposited by the Outhouse Flood mantles the top of the flood bar but is not exposed in the cutbank. A trench dug near the BLM outhouse here revealed at least 2 meters of medium sand with reworked pieces of Mazama tephra, indicating that the Outhouse Flood is probably younger than Mazama's age of 7.6 ka.

RM 64.5: A large Outhouse Flood boulder bar noses into the channel on river right. The abandoned grade above the community of Dant on river left leads to the dormant Lady Francis Perlite Mine, which was developed in the 1940s.

RM 64: Buckskin Mary Rapid is composed of remnant boulders from the Dant Debris Flow (river left).

RM 63.75: Stop 8. Dant Debris Flow Overlook

Wear sturdy shoes or boots for this stop! Take out on river right at a wooden sign marked *Trail*. Hike 100 m up the road toward Buckskin Mary Rapid and up a steep trail that leads up a talus slope between two cliffs. Enjoy the spectacular view of a massive Pleistocene debris flow that temporarily blocked the channel. Sandy deposits exposed in a railroad cut 300 m upstream may have been deposited when a lake formed behind the blockage. Bend Pumice in the lacustrine deposits indicates that the blockage was formed during or after the Bend–Tumalo eruptions of about 400 ka.

RM 63.4: Four Chutes Rapids formed by fluvially transported landslide debris.

RM 62.5: Stop 9. Type Outhouse Flood Bar

The giant bar on river left may have first formed during breaching of the Dant Debris Flow. Angular boulders at the upstream edge do not seem to have been transported far from their source. The Outhouse Flood may have left the rounded boulders on the top of the bar (near the outhouse), and historical floods deposited and scoured the fresh pebbles and cobbles on the upstream and downstream margins of the bar. Note the bent young "clipper ship" juniper trees, deformed by the flood of February 1996 as well as much older trees perhaps deformed by the 1861 flood. A cobble bar with a lower surface (mantled by railroad camp debris) is appended to the downstream end of the Outhouse Flood bar and was perhaps deposited by the 1861 flood.

RM 62: Caretaker Flat on river right has exposures of fine-grained and gravelly flood deposits. The visible white layer in the cutbank is an accumulation of tephra from the 7.6 ka eruption of Mt Mazama. A sand and gravel lens, stratigraphically between the Mazama tephra and a charcoal accumulation dated at 2,850±50 ^{14}C yr ago, is inferred to be an Outhouse Flood deposit. This surface was not overtopped by the February 1996 flood, but a lower surface, inset into the flat at the downstream end, records several floods of February 1996 magnitude during roughly the past 1,000 years.

RM 58.5: The John Day Formation dives below river level as the river enters the structural basin between the Mutton Mountains and the Tygh Ridge Anticline. For the remainder of the Deschutes River's course to the Columbia, the river-level bedrock is the Columbia River Basalt Group. The 4.9 Ma Juniper Flats basalt flow caps the left valley wall.

RM 55–54: Wapinitia and Boxcar Rapids are at the eroded toes of two overlapping landslides (Fig. 5). Note giant boulders cluttering the banks near Boxcar Rapids.

RM 51.5: Maupin City Park take out on river right.

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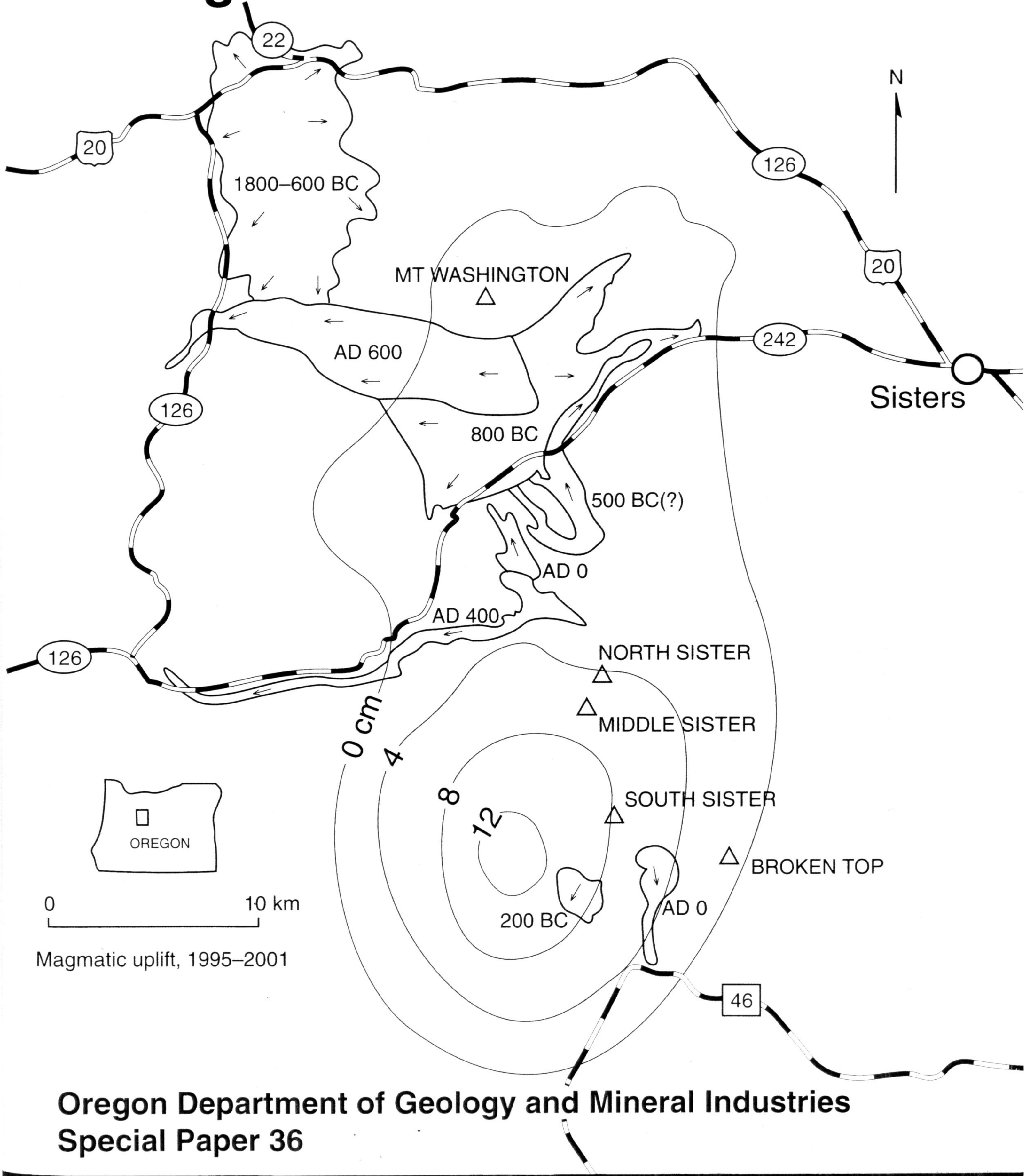

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Edited by
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Oregon State University

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FRONT COVER. Map of the Three Sisters area showing dated lava flows and magmatic uplift in centimeters between 1995 and 2001 (from Charles W. Wicks and Edward M. Taylor)
BACK COVER (clockwise from upper left). Olympic Mountains landsat image; Multnomah Falls; Dant Debris Flow; Deschutes River Canyon; Dune Paleosols

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