Geology and Geomorphology of the Lower Deschutes River Canyon, Oregon

Robin A Beebee, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403; rbeebee@darkwing.uoregon.edu

Jim E. O'Connor, U.S. Geological Survey, 10615 SE Cherry Blossom Drive, Portland, Oregon 97216; oconnor@usgs.gov

Gordon E. Grant, U.S. Forest Service Pacific Northwest Research Station, Corvallis, Oregon, 97331; gordon.grant@orst.edu

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.

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

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

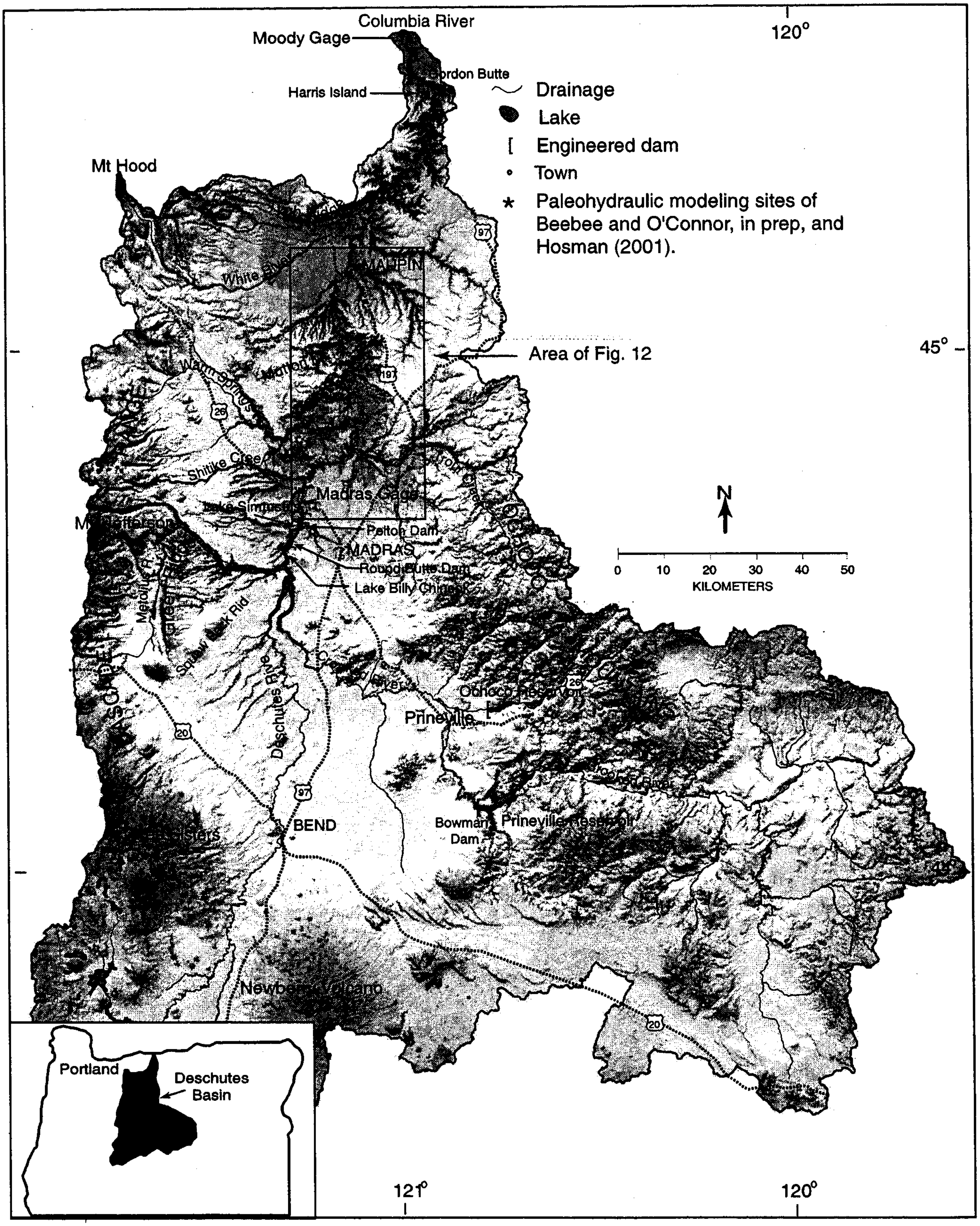

Figure 1. Drainage basin map of the Deschutes River.

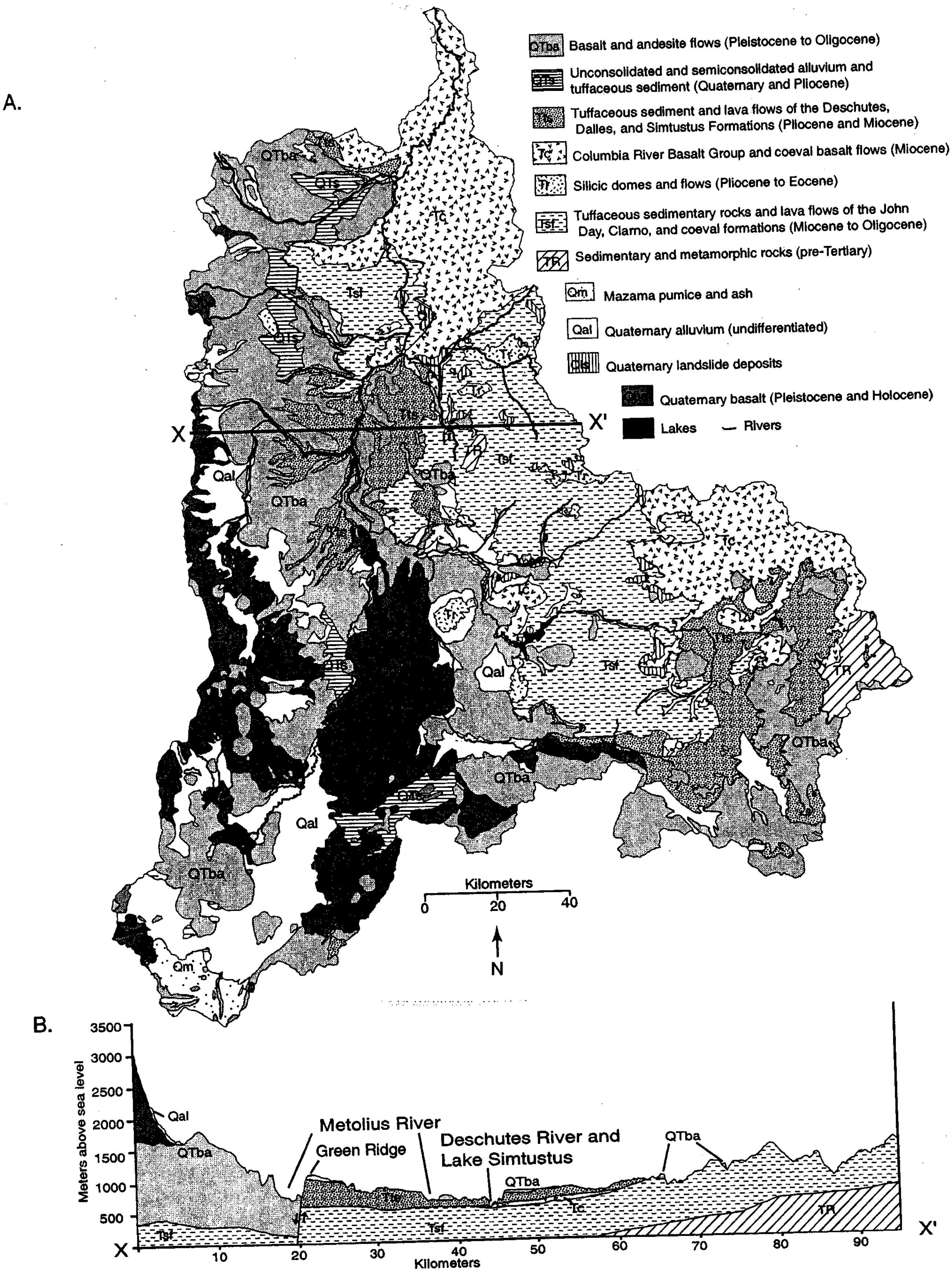

Figure 2. A. Geology of the Deschutes Basin generalized from Walker and McLeod (1991). B. Geologic cross section along line X to X' after Smith (1986).

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

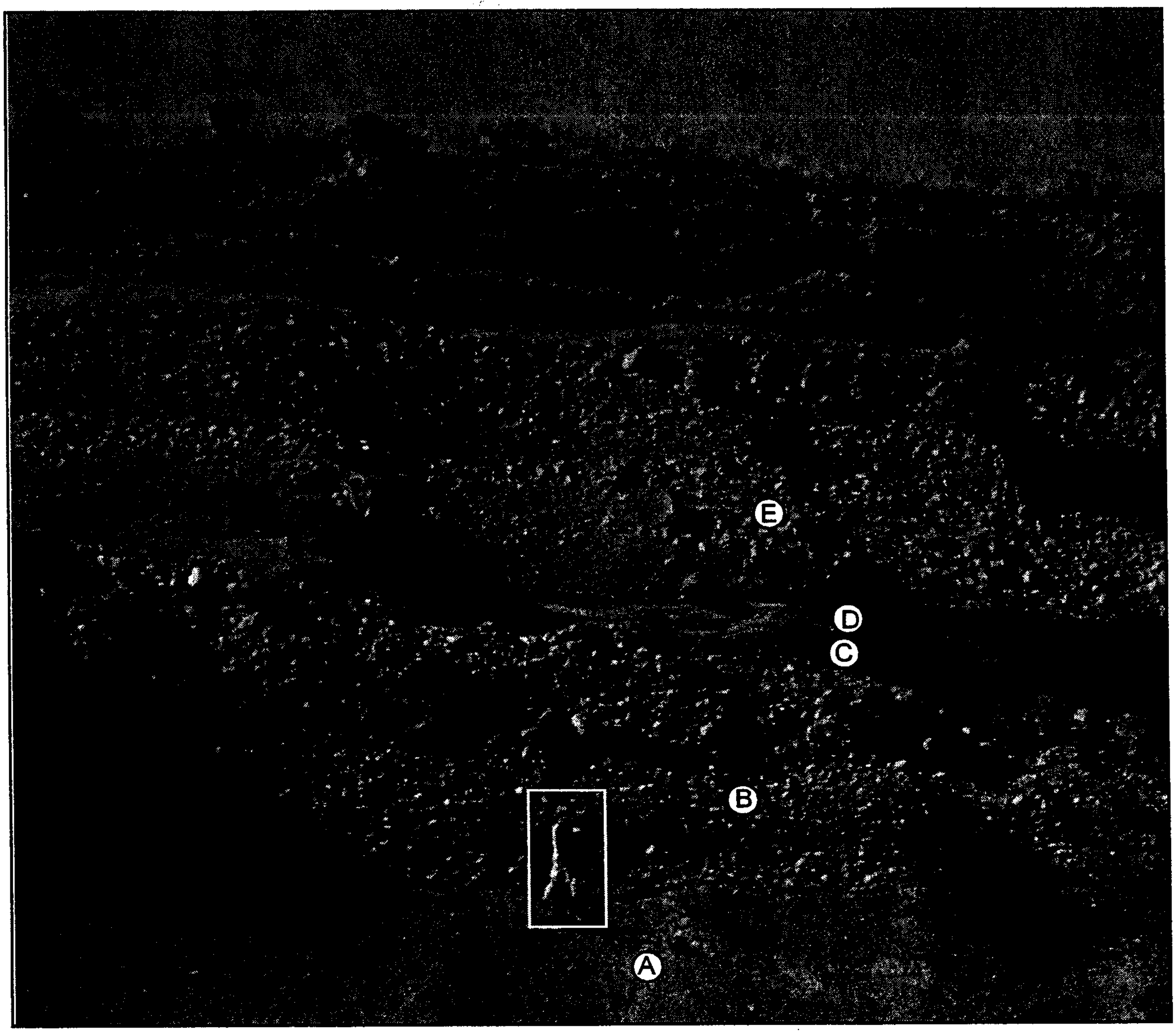

Figure 3. South Junction Terrace, River Mile 83.5 (Stop 3). A. Tilted strata of the John Day Formation. B. Fluvial gravel. C. Fluvial sand. D. Ashy lahar. E. Gravelly lahar. Unit E contains pumice clasts from a roughly 100,000 year old Mt Jefferson eruption (O'Connor and others, in press). The person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

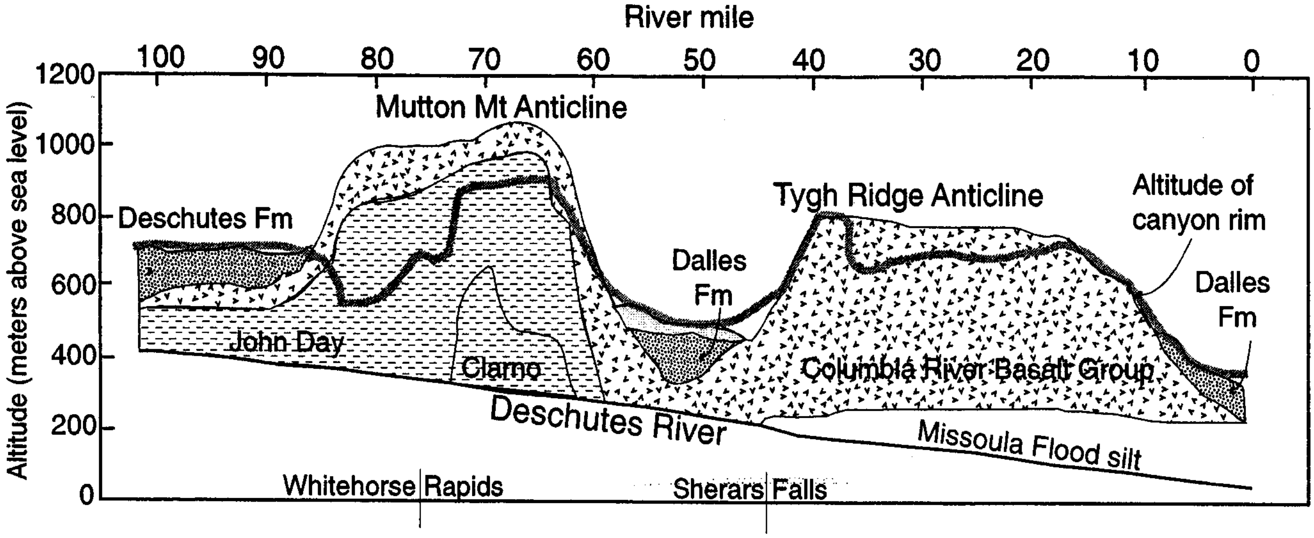

Figure 4. Longitudinal profile of the lower Deschutes River showing the exposed geology of the canyon. The gray line represents the altitude of the canyon walls superimposed on the total relief of the surrounding visible geologic formations and structures. Patterns follow Figure 2.

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

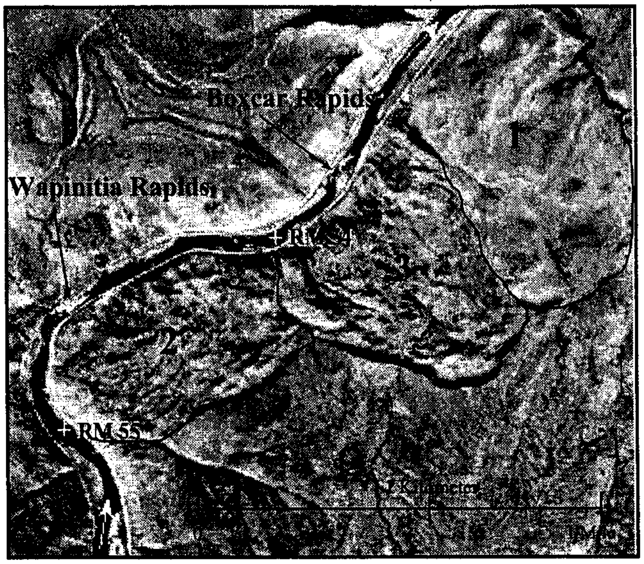

Figure 5. Air photo of overlapping landslides numbered 1–3 (oldest to youngest) at River Mile 55–53, and the rapids they created.

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

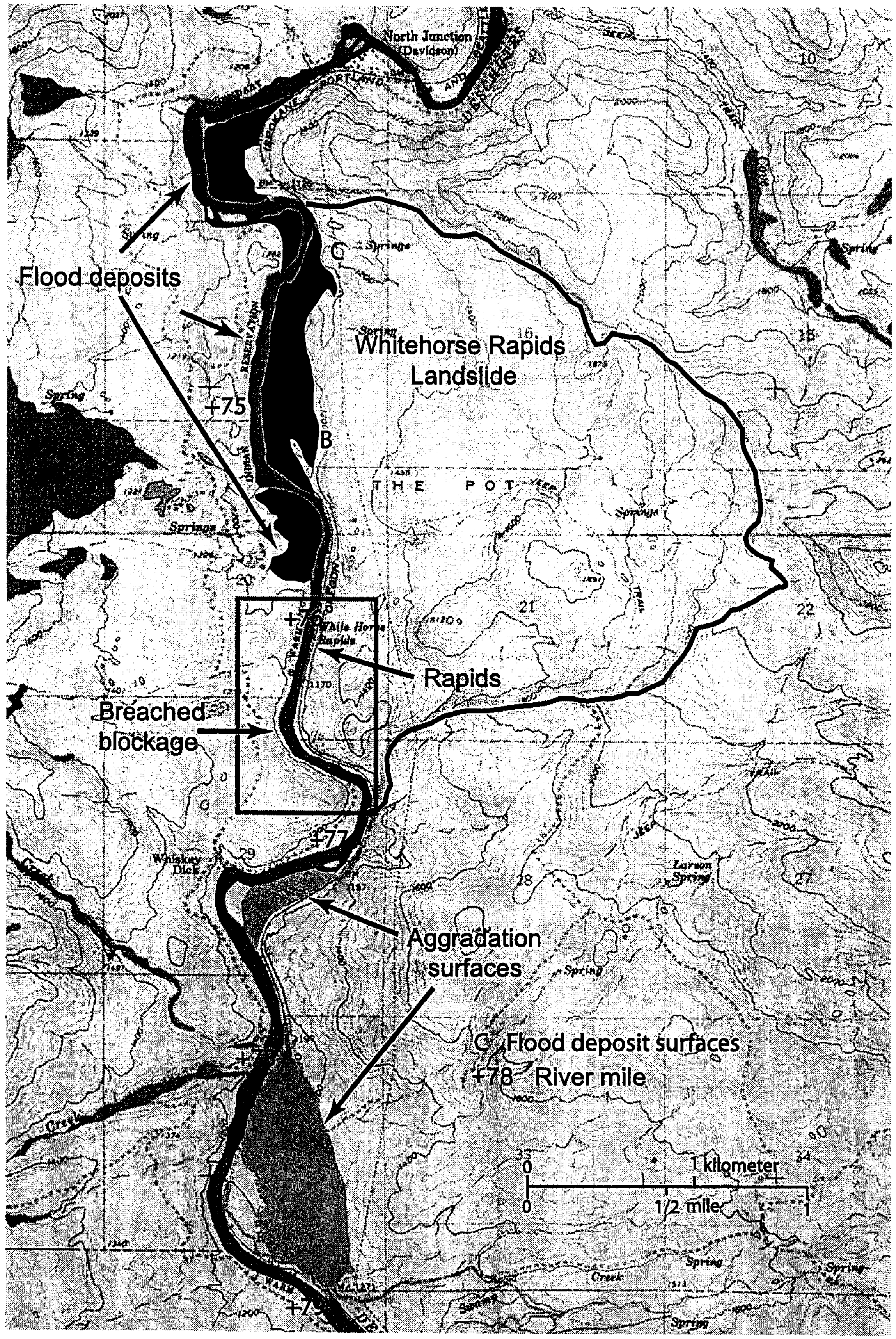

Figure 6. Geomorphic features related to the dam produced by the Whitehorse Rapids Landslide and the area of its outburst flood deposits plotted on the U.S. Geological Survey Kaskela 7.5-Minute Quadrangle.

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-

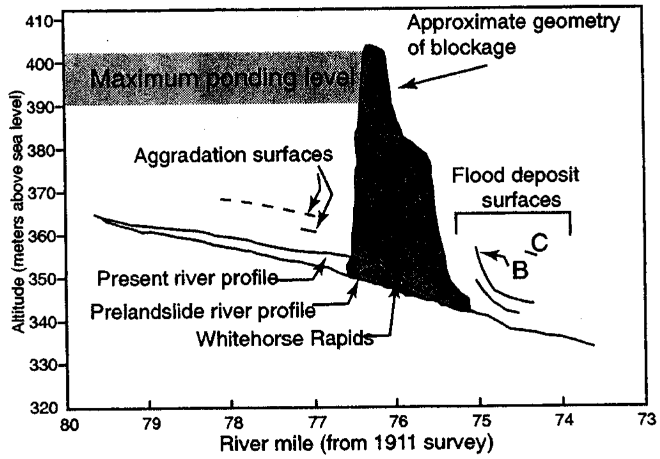

Figure. 7. Diagram of the breach site of the Whitehorse Rapids blockage showing the probable former river profile and the profile after the blockage. Surfaces B and C are labeled on Figure 6.

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

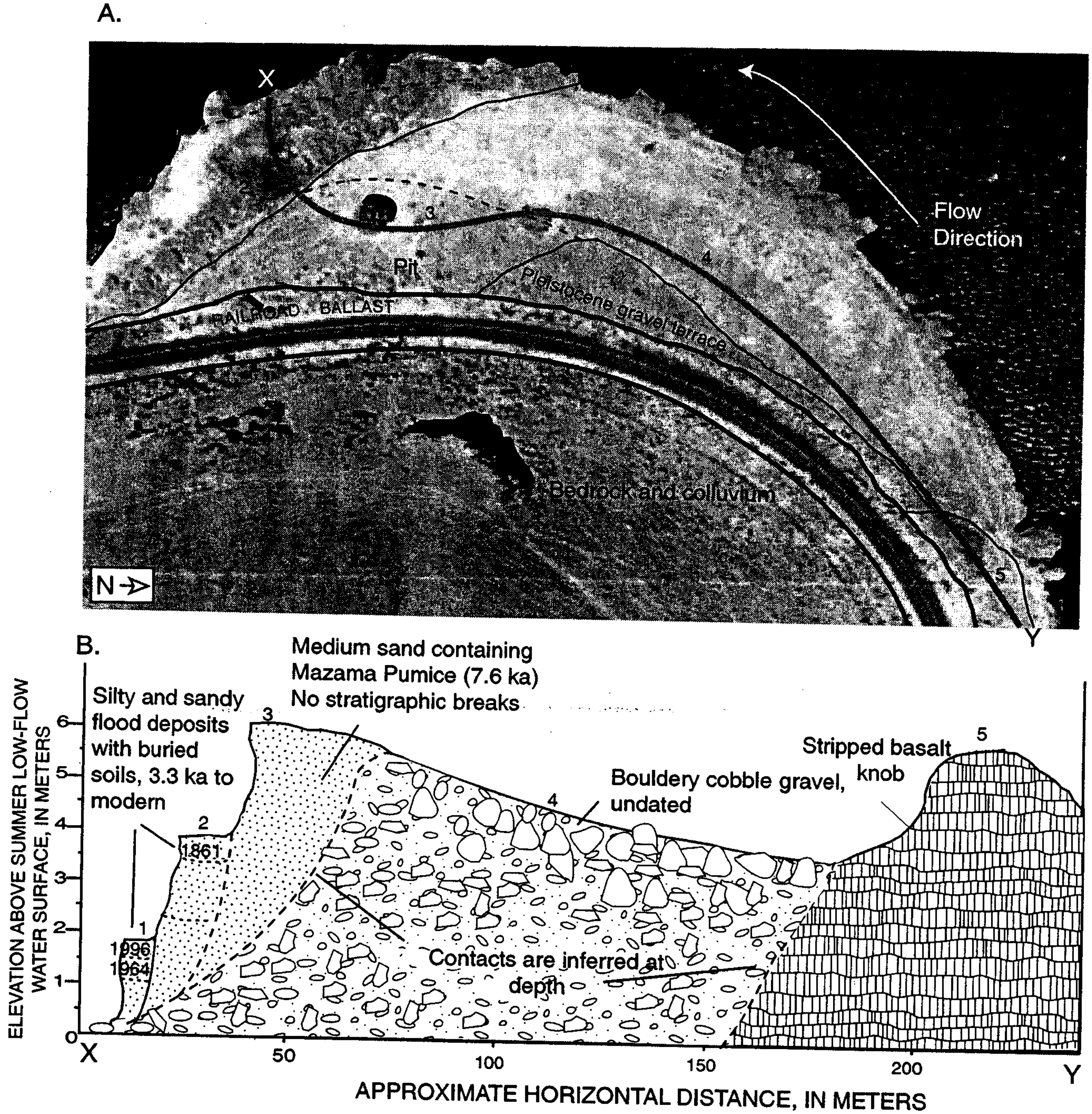

Figure 8. A. Air photo of an Outhouse Flood bar near Dant, River Mile 65 (Stop 7). B. Cross section of the flood bar along line X to Y.

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-

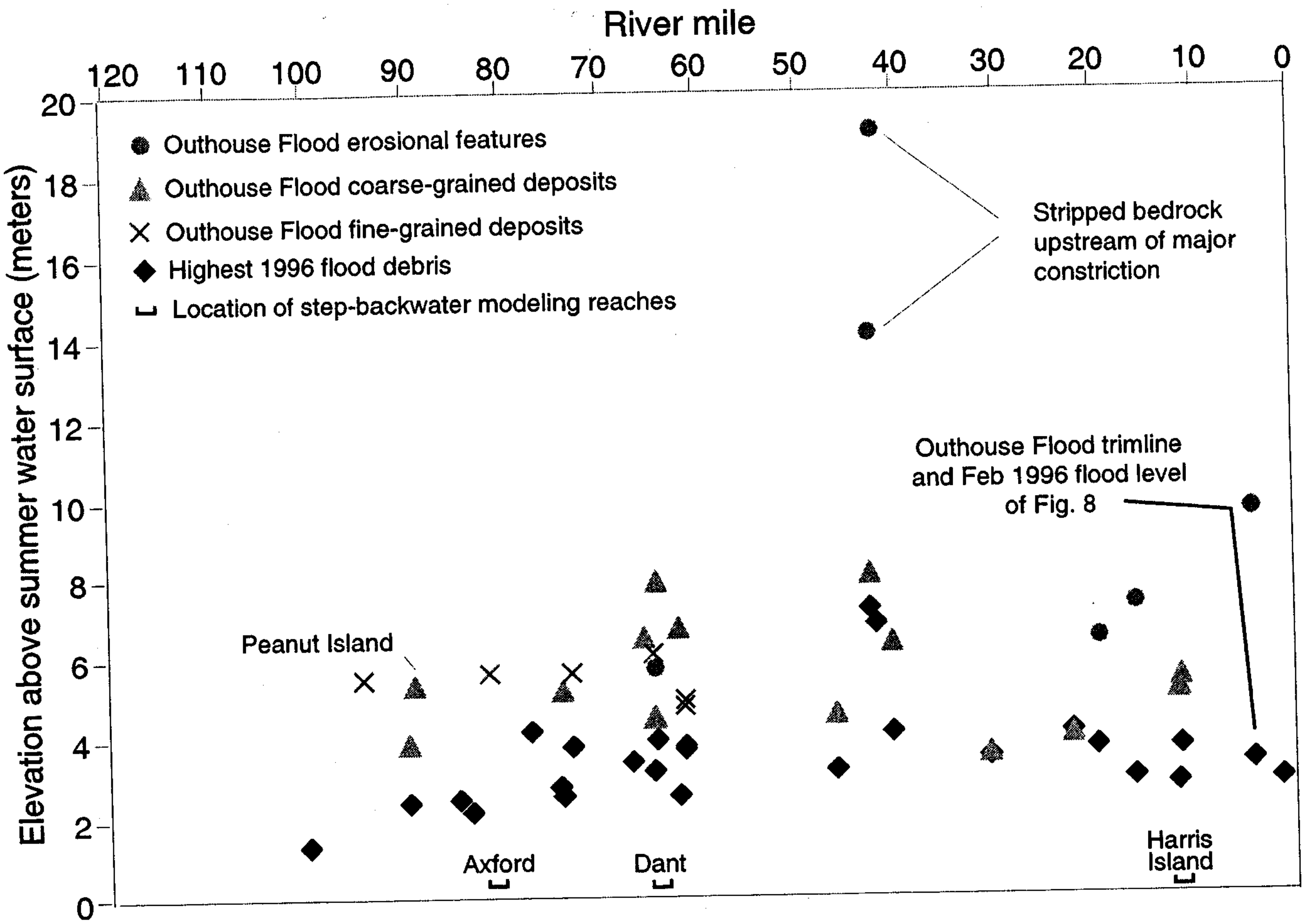

Figure 9. Comparison of the surveyed heights of paleostage evidence from the February 1996 flood and the Outhouse Flood.

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