Chapter 7

Field Trip Stop Descriptions

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INTRODUCTION

Fifteen sites within the Channeled Scabland have been selected as stops for the ground portion of this field conference. The stops were selected with the dual aim of visiting locations critical to the arguments for a catastrophic flood origin of the scablands as well as permitting an examination of the variability in both erosional and depositional features. The stop locations are plotted on a generalized geologic map of the Channeled Scabland (Fig. 7.1). Their coordinates are given in Table 1 (at the end of the chapter).

STOP 1: WILLIAMS LAKE GRAVEL PIT

The region southwest of Cheney is characterized by streamlined hills of Palouse loess separated by wide scabland channels eroded into Yakima basalt. As shown by Patton and Baker (Ch. 6, this volume), bars of flood gravel commonly extend both along the flanks and at the downstream end of these erosional remnants. The bars probably formed as a result of reduced turbulent action and sediment deposition in the wake-zone immediately downstream from the loess hill. Figure 7.2 shows the inferred flow pattern around the loess hill southeast of Williams Lake and demonstrates that individual gravel bars might have developed on both downstream flanks of the loess remnant and migrated toward the common center of the downstream wake-zone.

The composite photo of the pit face (Fig. 7.3) shows that the majority of foresets dip toward the southwest (left in figure). This is consistent with the hypothesis that the bar originated as a pendant to the remnant one mile to the northeast of this location. The upper gravel unit is poorly stratified but appears to indicate a more southerly or southeasterly dip, suggesting that individual bar slipfaces migrated in alternate directions as the pendant accreted.

Throughout the pit, one finds individual cobbles and boulders scattered among much finer gravel in the cross-beds (Fig. 7.4). This is common in flood gravel throughout the scablands (see, for example, Fig. 7.32). It is assumed that bed form migration on the bar surface combined with dispersive shear during the process of sediment avalanching down the slipface produced the regular size-sorting in the foresets. Therefore, the large clasts must have arrived by processes other than traction transport. One possible mechanism would be macroturbulent suspension transport. The presence of loess clasts in the deposit (Fig. 7.5) is also suggestive of suspension transport as tractive movement of such clasts would quickly lead to their disintegration.

STOP 2. MACALL-RITZVILLE ROAD

The inferred similarities between braided stream flow and certain characteristics of scour and deposition within the Cheney-Palouse scab-

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land tract (Patton and Baker, Ch. 6, this volume) can best be discussed with reference to the loess remnants and gravel bars along the Ritzville-Macall road. Although these morphologic relationships are best observed from the air, the ground view provides a better perspective of scale.

Over a distance of about 3 km, the road traverses the following features in a westward succession: a major pendant bar (Figs. 7.6 and 7.8), a scour hole within a secondary channel, a second pendant bar and two basalt knobs with attached, downstream aligned, pendant gravel bars

(Fig. 7.7). To the west of this last bedrock outcrop, a train of giant current ripples can be observed climbing up the adverse downstream slope of a scour hole. According to Patton and Baker (Ch. 6, this volume), these ripples are developed on gravel less than a meter thick in the ripple troughs. Relatively thin gravel is typical of bars in the area. The ones accessible from this road may average 10 to 15 meters in thickness. These thicknesses are substantially less than the reported 40 meters of fill in the Quincy Basin (Stop 7) and may relate to the shallower water depths and generally more uniform flow conditions than those responsible for the Ephrata Fan expansion bar.

Figure 7.1. Generalized geologic map of the Channeled Scabland (after Bretz, 1959, his Plate 1) with field trip stop locations superimposed.

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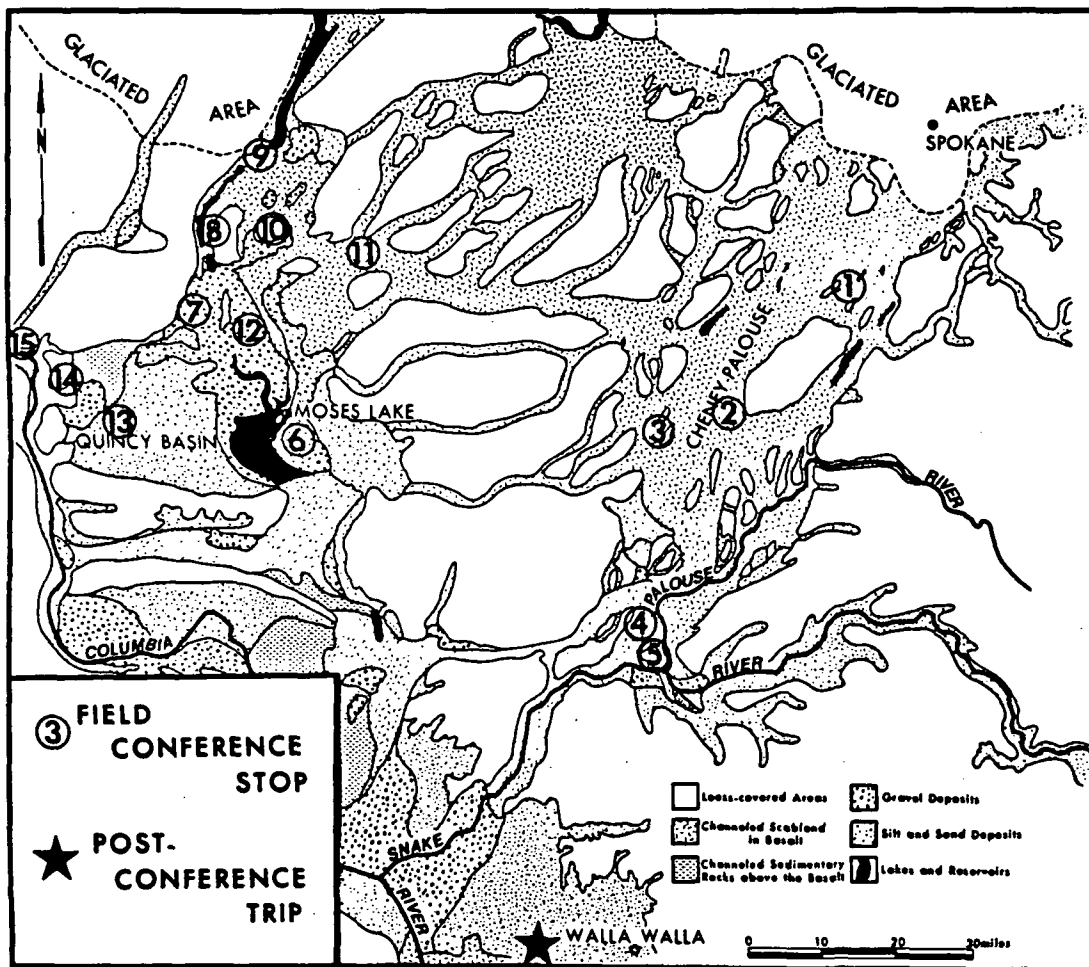
The numerous bars along this stretch of road all are attached to a downstream bedrock step created by a resistant basalt flow (Patton and Baker, Ch. 6, this volume). Their precise location may also have been aided by the transition from upstream constrictions between two loess islands to a major channel expansion (Figs. 7.6).

Further south (downstream), this channel maintained a more uniform width (Fig. 6.2) and its floor consists largely of stripped basalt with large areas of scabland morphology (Fig. 7.8).

In terms of channel bifurcation and sediment deposition, patterns of similarity exist between the Cheney-Palouse tract and modern braided streams. For example, the loci of sediment deposition correspond to sites of reduced current velocity or turbulence. In Cheney-Palouse (Fig. 7.6), as in modern braided streams (Boothroyd and Ashley, 1975; Nummedal and others, 1974), such zones generally occur where channels of higher elevation and less discharge rejoin a larger channel skirting the bar margins. The sand-wedge slipfaces of Rust (1972) and Boothroyd and Ashley (1975) appear to have their catastrophic equivalents in some of the pendant gravel bars (and expansion bars) of the Cheney-Palouse. Nevertheless, it is important to remember that the hills of the Cheney-Palouse, which by-and-large are responsible for the braiding (Patton and Baker, Ch. 6, this volume) are erosional rem-

Figure 7.2. Simplified morphologic map of a region southeast of Williams Lake (Part of Fig. 7.1 inset for location). Mapped from U.S.G.S. 15' topographic map, Cheney quad.
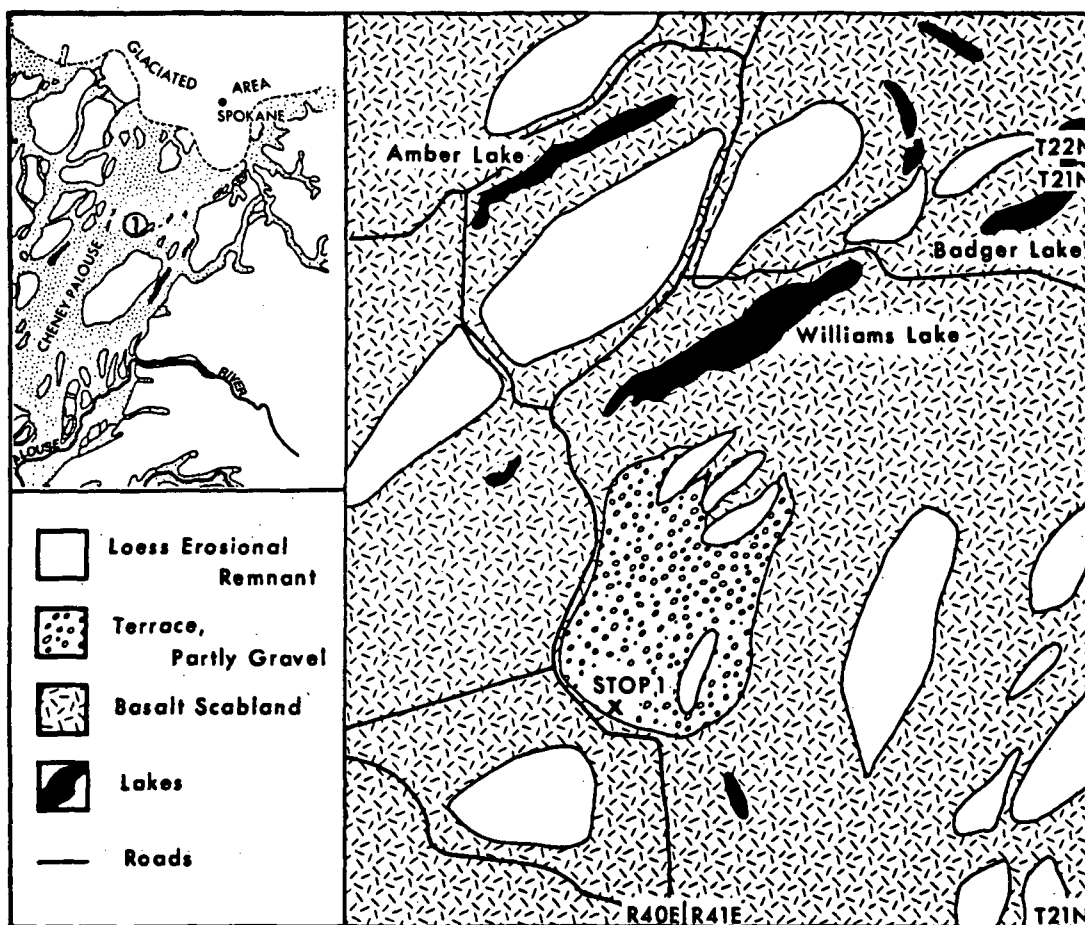

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Figure 7.3. Composite photograph of the face of the gravel pit southeast of Williams Lake. The majority of the foresets dip toward the southwest (left).

Figure 7.4. Close-up of bar cross-stratification. Large cobbles (about 10 cm long) are dispersed throughout the finer cross-bedded gravel.

Figure 7.5. Loess clasts are common throughout the gravel bar. This one measures about 15 x 15 cm.

STOP 3. MARENGO RAILROAD CUT

As shown in Figures 7.6 and 7.9, the tracks of the Chicago, St. Paul, Milwaukee and Pacific Railroad cut through the pendant bar at the south end of a large loess remnant about ½ kilometer west of the Marengo siding. The origin and in-

nants of a pre-flood geological formation and as such genetically totally unrelated to braided stream bars.

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Figure 7.6. Morphological maps of the Ritzville-Macall road traverse across the Cheney-Palouse scabland tract. A is a part of Fig. 7.1 for location. B identifies the setting of Stops 2 and 3 relative to bars and loess hills of the Cheney-Palouse tract (mod. from Fig. 6.2). C shows morphologic detail in the vicinity of Stop 2 (modified from Fig. 6.7).

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Figure 7.7. Oblique aerial view toward the northeast of the Macall area. Compare maps in Fig. 7.6 for identification of the individual features. Do not confuse the Macall-Ritzville road (across the center of the photo) with the railroad tracks (lower right) (photograph 6239 by John S. Shelton).

ternal stratification of this bar are probably similar to what was observed at the Williams Lake gravel pit. Sedimentary structures, however, are not that well displayed in this section.

The railroad-cut provides excellent insight into the Pleistocene stratigraphy of the Cheney-Palouse tract. The open-work, coarse flood gravel interbedded between loess units containing well-developed soil horizons constitute evidence for two floods, one perhaps pre-Bull Lake, the younger probably early Pinedale (see Table 2.1). The stratigraphic section measured from the top of the cut in Figure 7.10 by Patton and Baker is presented in Figure 7.11 (See also Baker, Ch. 2, Fig. 2.5, this volume). The lower gravel has all

the fabric characteristics of flood gravel elsewhere in the scablands. It is distinguished by a thick weathering rind and is overlain by a dark yellowish brown loess capped by a petrocalcic horizon (K-horizon) strongly suggestive of its pre-Bull Lake age (Fig. 7.12). Overlying the petrocalcic horizon is more loess with other soil profiles. These younger soils also have mature profiles, textural B horizons and calcareous Cca horizons (Fig. 7.13). These caliches, however, are less thoroughly cemented and do not qualify as K-horizons (Baker, 1977, p. 408). They comprise the Palouse Formation which is interpreted as Bull Lake in age. Overlying this sequence is a second layer of flood gravel, significantly less

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Figure 7.8. Oblique aerial view toward the south of the Macall area. See maps in Fig. 7.6 for location (photograph 6235 by John S. Shelton).

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weathered than the lower unit. The section is capped by the modern soil profile developed in Late Pinedale (and Holocene) loess. Elsewhere in the Cheney-Palouse scabland tract, Patton and Baker (Ch. 6, this volume) have found additional evidence of multiple flood events.

STOP 4.
PALOUSE-SNAKE
DIVIDE
CROSSING

The region around the Palouse-Snake River junction contains, next to Grand Coulee, perhaps the most impressive morphologic evidence of

Figure 7.9. Oblique aerial view toward the southwest of the Marengo loess hill. Stop 3 is in the railroad-cut through the pendant bar visible in the upper right (arrow).
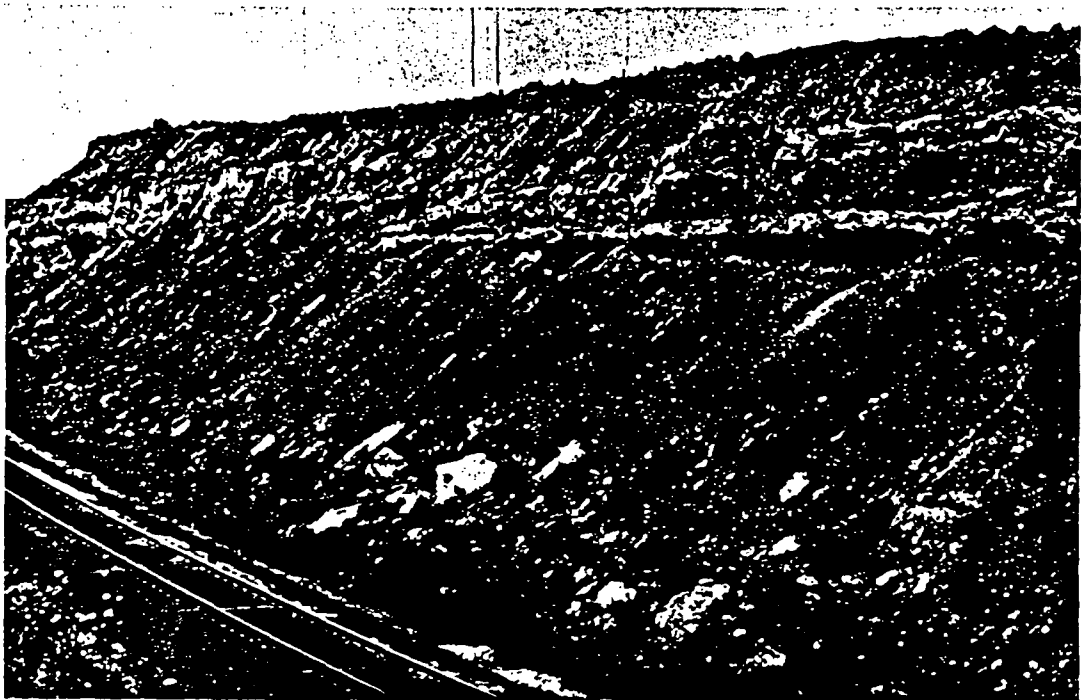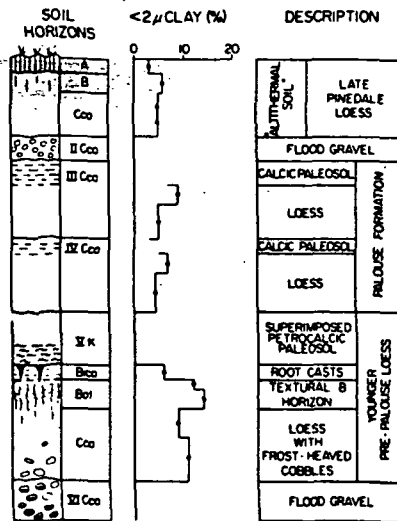

Figure 7.10. The Chicago, St. Paul, Milwaukee and Pacific Railroad cut through the pendant bar at the downstream end of the Marengo loess hill.

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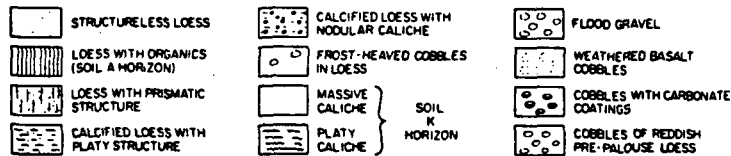
Figure 7.11. Measured stratigraphic section at the Marengo railroad-cut (modified from Fig. 2.5).

EXPLANATION

STRUCTURELESS LOESS		CALCIFIED LOESS WITH NODULAR CALICHE		FLOOD GRAVEL
LOESS WITH ORGANICS (SOIL A HORIZON)		FROST-HEAVED COBBLES IN LOESS		WEATHERED BASALT COBBLES
LOESS WITH PRISMATIC STRUCTURE		MASSIVE CALICHE } SOIL K HORIZON		COBBLES WITH CARBONATE COATINGS
CALCIFIED LOESS WITH PLATY STRUCTURE		PLATY CALICHE }		COBBLES OF REDDISH PRE-PALOUSE LOESS

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Figure 7.12. Close-up view of the lower flood gravel at the Marengo section. The basalt cobbles have thick weathering rinds and are overlain by a pre-Bull Lake loess.

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catastrophic flooding. In the pre-flood drainage pattern, the Palouse River flowed toward the southwest from Washtucna, down the lower Washtucna Coulee (Fig. 7.14). With the late Pleistocene Missoula Flood rushing down the Cheney-Palouse tract, most of the water took a shortcut directly across the Palouse-Snake divide south of Hooper and Washtucna. Bretz (1959, p. 40) declares: "There is no more significant area than this divide for testing rival theories." The bedrock divide is 16 kilometers across and with its loess cap at least 100 meters higher than the floor of the preflood Palouse Valley. The flood overflowed this valley and overtopped the divide. As a result of the overtopping, it stripped nearly all loess off the divide, leaving only a few narrow, streamlined hills near the summit (Figs. 7.15, 7.16 and 7.17). These 50-meter high hills are probably subfluvial in origin (Baker, 1973a). Flanking these hills are the 125-meter deep Palouse Canyon to the east (Fig. 7.17) and the dry cataract next to the H U Ranch to the west. Two large rock basins are found near the very summit of the divide crossing (Fig. 7.14). As a

result of the flood, the lower Washtucna Coulee was left without any through-drainage, and today contains only small alkaline lakes. The Palouse River was diverted to the new gorge carved by the flood into the highly jointed bedrock south of Washtucna. The river itself occupies what appears to be an inner channel (Shepherd and Schumm, 1974) developed subfluvially during the erosion of the canyon. Headward recession of the cataract initiated on the north wall of the Snake River Canyon produced Palouse Falls, where the river today drops through 60 meters of free fall from the upper to the lower canyon (Fig. 7.18).

This is part of the erosional landscape which Flint (1938b) attributed to the action of "leisurely meandering glacial streams, no larger than the Snake River of today," an idea which Bretz and others (1956, pp. 1015-1020) dismantle by a meticulously detailed analysis of the flow patterns across the Palouse-Snake divide. Bretz (1959, p. 41) concludes: "The scabland features just enumerated are utterly impossible erosional forms for such streams [i.e. leisurely meandering] to have made."

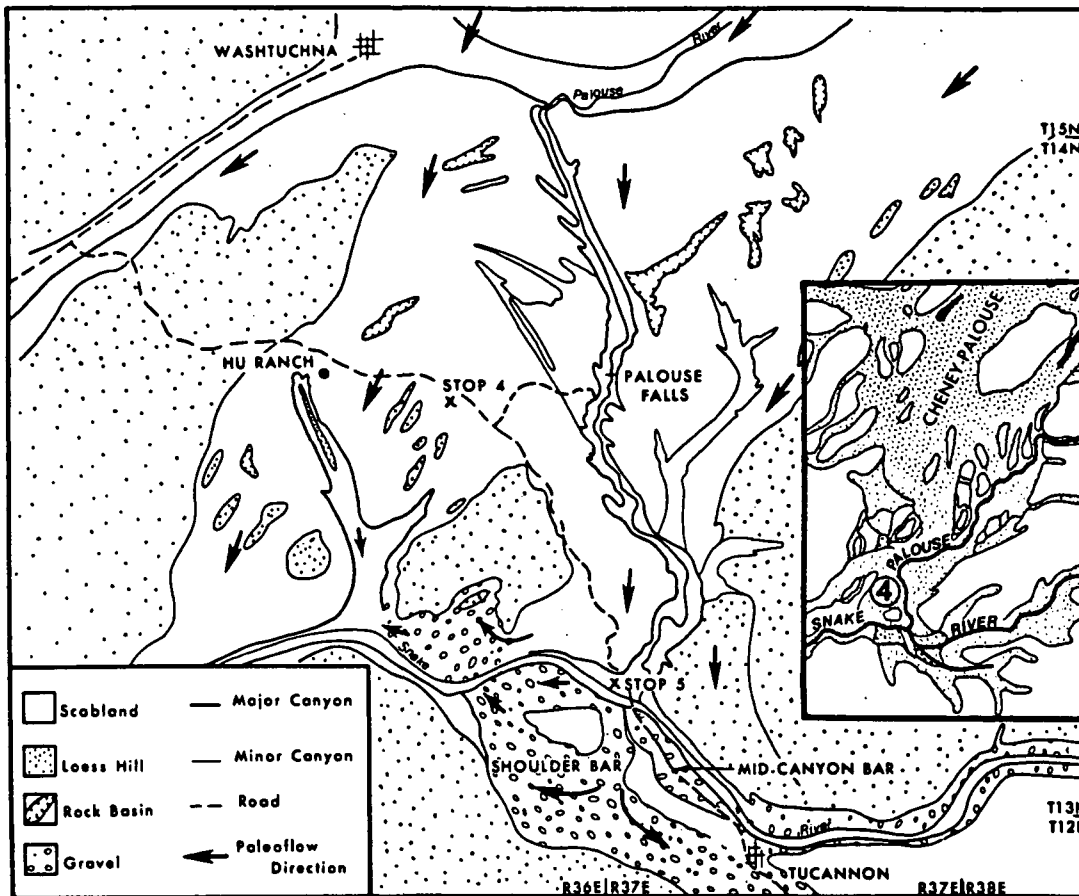Figure 7.13. Section of the Palouse Formation at the Marengo railroad cut.

Figure 7.14. Generalized morphological map of the region surrounding the Snake-Palouse River junction. Mapped from U.S.G.S. 15' topographic maps, Starbuck and Haas quads. Arrows indicate the inferred paleoflow directions.

STOP 5. PALOUSE-SNAKE JUNCTION

From this vantage point underneath the Union Pacific Railroad trestle, one can reconstruct the pattern of flow as the flood currents swept across the Snake River Canyon from the north. South of the Snake River at this point are the only two high-elevation flood gravel deposits found anywhere along the canyon of the lower Snake River. These are Shoulder Bar and Mid-Canyon Bar (Fig. 7.14). Shoulder Bar (Bretz, 1928b, p. 657; Bretz and others, 1956, p. 1020) represents a square mile of flood gravel with a surface elevation 150 meters above the valley floor. Flow across the bar was northward as
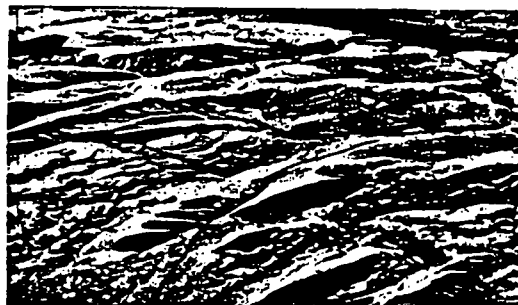

Figure 7.15. Oblique aerial view toward the southeast of streamlined Palouse loess hills just east of the H U Ranch. Flood flow direction was from lower left to upper right.
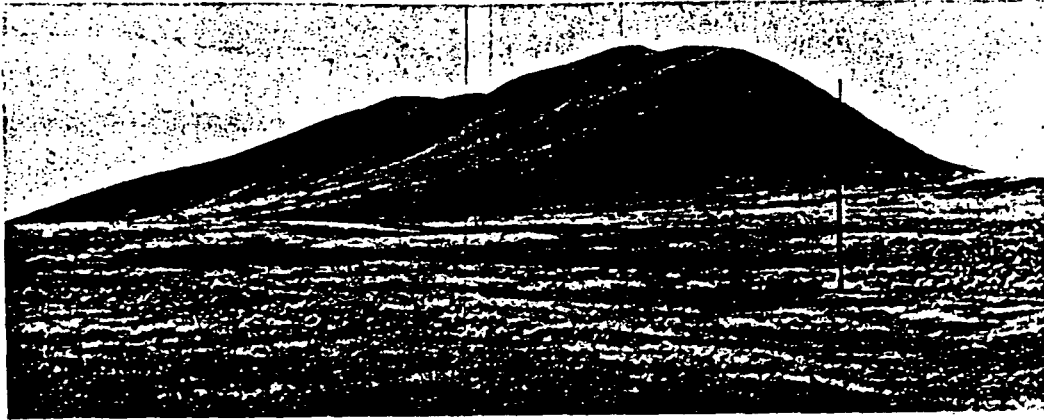
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Figure 7.16. Ground view of the prominent loess hill in the lower right of Fig. 7.15.

Figure 7.17. Oblique aerial view toward the northwest across the western part of the Palouse-Snake divide. In the foreground is the lower part of the Palouse River Canyon with the falls off the edge of the picture to the right (photograph 2042 cr by John S. Shelton).
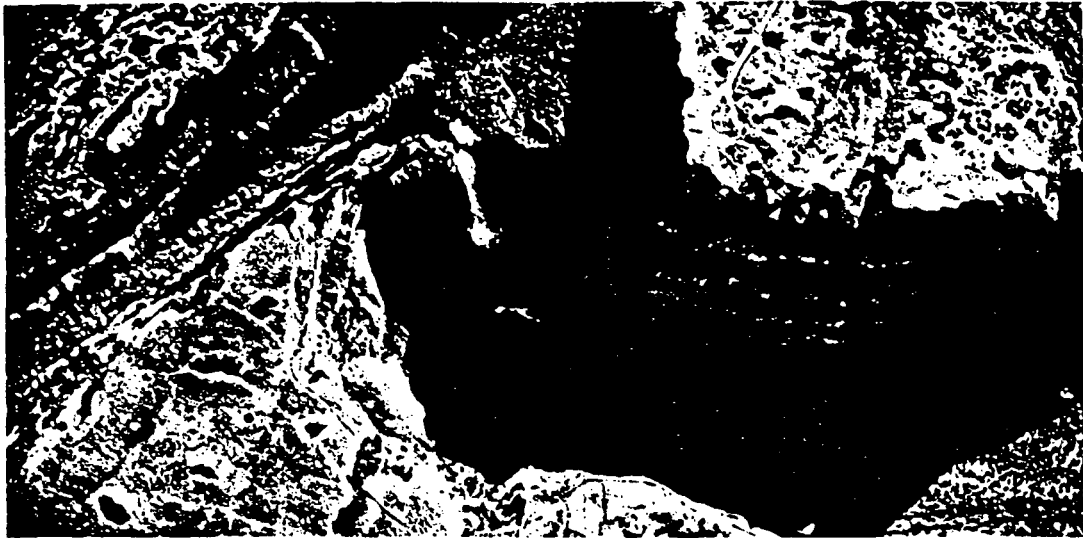
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Figure 7.18. Aerial view of Palouse Falls. Note the numerous joints in the bedrock to the right of the falls. The Palouse River Canyon upstream of the falls was eroded along one such joint set.

Figure 7.19. Oblique aerial view toward the southeast across the Snake River immediately downstream of the Palouse confluence. Refer to map in Figure 7.14 for locations. Shoulder Bar has steeply dipping foresets and gravel ripples both demonstrating flow northward into the Snake River Canyon. Mid-Canyon Bar is visible in the upper left corner of the photograph (photograph 6245 by John S. Shelton).

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demonstrated both by large foresets dipping *northward into* the Snake Canyon and giant current ripples covering the surface (Fig. 7.19). The gravel consists of a mixture of scabland basalt and well-rounded Snake River cobbles and pebbles. The only explanation for this feature is that strong flood currents from the mouth of the Palouse Canyon carried gravel across the Snake River valley *up* the south flank to an elevation of 150 meters, then were deflected around the basalt hill north of Shoulder Bar and returned to the Snake River further west. From there, flood waters followed the present river further downstream (Fig. 7.14). As a consequence of flow divergence and reduced current velocity, a large amount of the sediment load was dropped to build Shoulder Bar.

Some of the flow across the Snake River Canyon was deflected upstream to build the Mid-Canyon Bar adjacent to the modern stream course and Trickle Bar behind the saddle in the bedrock across from the Palouse River mouth (Fig. 7.14). The morphology of this saddle itself is suggestive of an origin by scour during the flood. The trough (fosse) on the landward side of Mid-Canyon Bar (Fig. 7.19) appears to reflect the location of a thread of high turbulence along the side of the steep bedrock flank. Ripples and internal cross-stratification of the point bar between the Union Pacific tracks and the Snake River demonstrate the flood origin of this feature as well (Fig. 7.20). Thus a significant amount of flow was discharged directly down the Snake River Canyon without being detoured across Shoulder Bar. The amplitude of these giant ripples is demonstrated in Figure 7.21. Large basalt columns, probably derived from near-by outcrops attest to the competency of the flow (Fig. 7.22).

The back-rush up the Snake River, as evinced by the topography and stratification of the Mid-Canyon Bar, was capable of eroding Snake River

Figure 7.20. Oblique aerial view toward the east of an unnamed flood bar between the present course of the Snake River and the Union Pacific Railroad. Giant current ripples demonstrate flow down the Snake River Canyon (toward the bottom of the photo).

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Figure 7.21. Ground view of the surface of the bar
shown in Fig. 7.20. Note man for scale (arrow).

Figure 7.22. Basalt column excavated in the gravel pit
on the bar shown in Fig. 7.20. The column is nearly 2 m
in diameter.

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gravel and redepositing it with foresets dipping upstream all the way to Lewiston, Idaho, 110 km distant (Bretz, 1969, p. 527).

As an interesting archaeological sidelight on this part of the country, the following is repeated from Webster and others (1976, p. 18):

"Upstream along the Palouse River, approximately 2 miles from this point, was the Marmes Rockshelter. This archaeological site received worldwide attention in the spring of 1968 when human remains were discovered *in situ* 14 feet beneath the surface of the modern flood plain. These remains were established reliably as being at least 10,000 years old—the oldest well-documented human remains in the New World. Numerous artifacts, cultural features and animal bones were associated directly with the human remains. Because the site was to be flooded by impoundment behind Lower Monumental Dam in less than a year, emergency salvage excavations were begun in May 1968 and continued through February 1969 when the

reservoir and site were flooded. Marmes Rockshelter contains an unparalleled stratigraphic and cultural record spanning more than 10,000 years."

No formal stops are planned between the Palouse-Snake River junction and Moses Lake. If time permits, however, a quick stop will be made at Roxboro in Lind Coulee to view some of the best-developed giant current ripples in the Channeled Scabland (Figs. 7.23 and 7.24). The ripples display a distinct increase in spacing, lateral crest continuity and height toward the south side of the channel where, supposedly, the current velocity was the highest. Measurements yield a typical height of 3.5 meters, a spacing of 78 meters and a water depth (from high-water marks on the coulee flanks) of 80 meters at this ripple train (Baker, 1973a, p. 60, Table 2). From these data and a measured regional slope of 0.002, he calculated a current velocity of 17 m/sec, a dis-

Figure 7.23. Part of U.S. Bureau of Reclamation topographic map of the Columbia Basin Project. The 2-foot contour interval provides an excellent display of the morphology of the Roxboro ripple field. Section lines provide scale. North is toward top.

charge of about 3 x 10⁰ m³/sec and a Froude number of about 0.7. Due to the relatively uniform flood flow through this part of Lind Coulee, these are probably some of the most precise paleohydraulic calculations that can be made. The results are judged to be representative values for many of the east-west trending coulees connecting the Cheney-Palouse scabland tract with the western regions of the plateau.

STOP 6. MOSES LAKE DUNE FIELD

The fine sand deposited by the Missoula Flood at the distal margin of the Ephrata Fan throughout the central Quincy Basin has been subject to extensive aeolian reworking. Small sand dune fields are common throughout the scablands, but nowhere is the dune field as extensive as to the south and west of Moses Lake.

The western edge of the field, at Winchester Wasteway about 30 km west of Moses Lake, is characterized by a series of semi-parallel east-west trending sand ridges (Fig. 7.25). The ridges

Figure 7.24. Oblique aerial view to the south across Lind Coulee at the Roxboro ripples. Flow was from left to right. North is toward bottom.

today are all stabilized by sagebrush and grass. Actively migrating slipfaces and recognizable parabolic dune forms increase in frequency toward the east (Plate 1 and Fig. 7.26). That portion of the dune field which extends into the agricultural land on the east side of Potholes Reservoir is largely active. The parabolic dune form is readily apparent both here and on the west side of the reservoir (Plate 1).

The orientation of the parabolic dunes demonstrates wind-driven sand transport from west to east, a direction consistent with the prevailing as well as dominant westerly winds recorded at the Grant Co. airport at Moses Lake. It appears that as the parabolic dune form migrates, it leaves behind a series of linear parallel to sub-parallel ridges, some of which may become buried and re-excavated as a new active dune passes over an older partly stabilized sand ridge (Fig. 7.27).

The development of a more or less contiguous field of parabolic dunes appears consistent with the rather abundant sand supply and unidirectional winds of the area. A somewhat more restricted sand supply seems to characterize adjacent scabland areas. For example, the Wahluke Slope has beautiful examples of single, large-scale parabolic dunes migrating eastward, inside of which are fields of individual barchanoid dunes.

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STOP 7. EPHRATA GRAVEL PIT

To reach this gravel pit, one drives east on Washington State route 282 from Ephrata toward Moses Lake. Immediately after ascending a steep, 15-meter high incline south of Ephrata, the gravel pit is entered on the south side of the road. The pit is operated by Columbia Concrete Products. The steep incline represents the western margin of the large Ephrata Fan system, an extensive coarse gravel unit deposited as flood waters from the lower Grand Coulee expanded into the wide Quincy Basin after leaving the last coulee constriction at Soap Lake (Plate 2, Fig. 7.28). Drainage into the Quincy Basin also came from Dry Coulee and Long Lake Coulee which, together with the lower Grand Coulee, all drained the large Hartline Basin to the north. Flow also came as a broad front across the divide south of upper Crab Creek. These drainage lines complicate somewhat the paleoflow pattern along the eastern flank of the fan. The dominant shape of the deposit, however, is clearly that of a fan with its apex (but not its highest elevation) at Soap Lake, demonstrating that the source of the bulk of the sediment was the Grand Coulee.

The deposit must have been built as a subfluvial bar, not as a common alluvial fan on which the active channels constantly change location but never submerge the entire fan at one time. The highest portions of the fan, near Ephrata, stand 90 meters higher than the scoured rock bottom of Soap Lake (Bretz, 1969, p. 528) about 8 km to the north. This steep adverse slope (0.01) can only be explained by a rapidly diverging flow pattern and shoaling to the south of the Soap Lake efflux section. Baker (1973a, p. 15) reconstructs a ponded water surface at 425 meters elevation throughout the Quincy Basin based on high-water marks. If this level is coincident with maximum scour at Soap Lake, the flow depth would have changed from about 100 meters at Soap Lake to a mere 10 meters east of Ephrata. Further hydraulic calculations by Baker (1973a, his Plate 1) yield a peak discharge for the Soap

Figure 7.25. The western part of the Moses Lake sand dune field is characterized by a series of stabilized linear sand ridges, probably the remnants of migrating parabolic dunes.
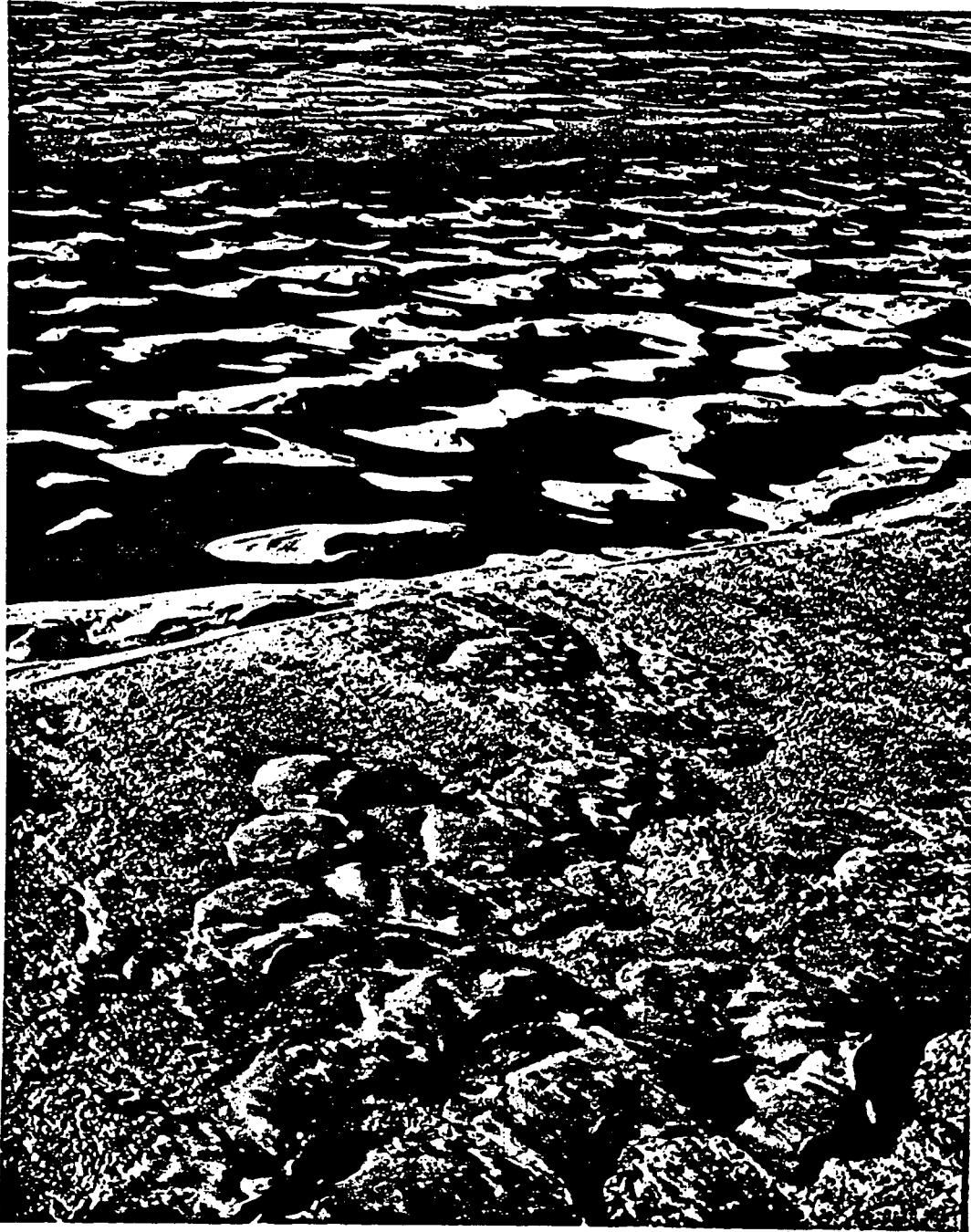
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Figure 7.26. Oblique aerial view to the west of the central part of the sand dune field at the Potholes Reservoir. (photograph 2029 cr by John S. Shelton).

Lake section of about 5×10^6 m^3/sec. The maximum known thickness of sedimentary fill in the Quincy Basin is 40 meters (Bretz and others, 1956, p. 969).

The surface of the Ephrata Fan displays a series of lobate depositional units commonly bounded on their downstream margin by slipfaces (now inactive and somewhat modified) (Figs. 7.29 and 7.30). This surface morphology indi-
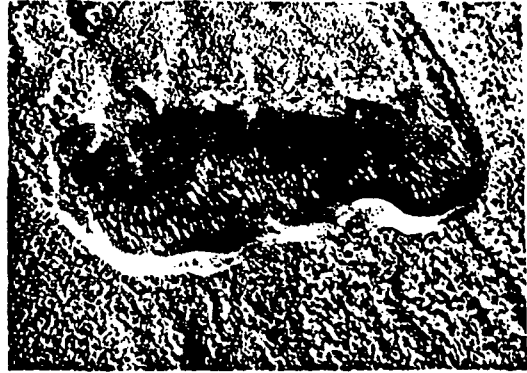

Figure 7.27. Vertical aerial view of a parabolic dune to the east of the Potholes Reservoir. Note the burial and re-excavation of linear sand ridges.
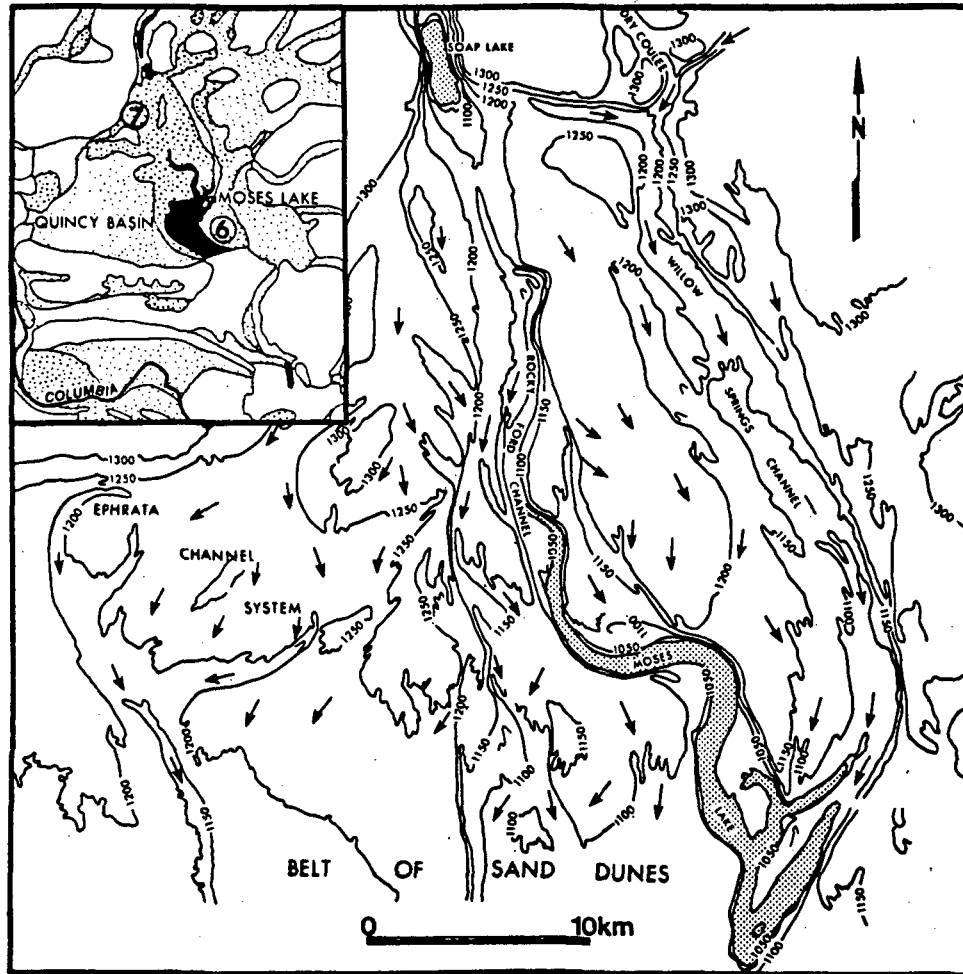

Figure 7.28. Topographic map of the Ephrata Fan complex in the upper Quincy Basin. Arrows indicate inferred surface flow directions. Modified from Bretz (1959, his Fig. 20, p. 33). Contours in feet above m.s.l.
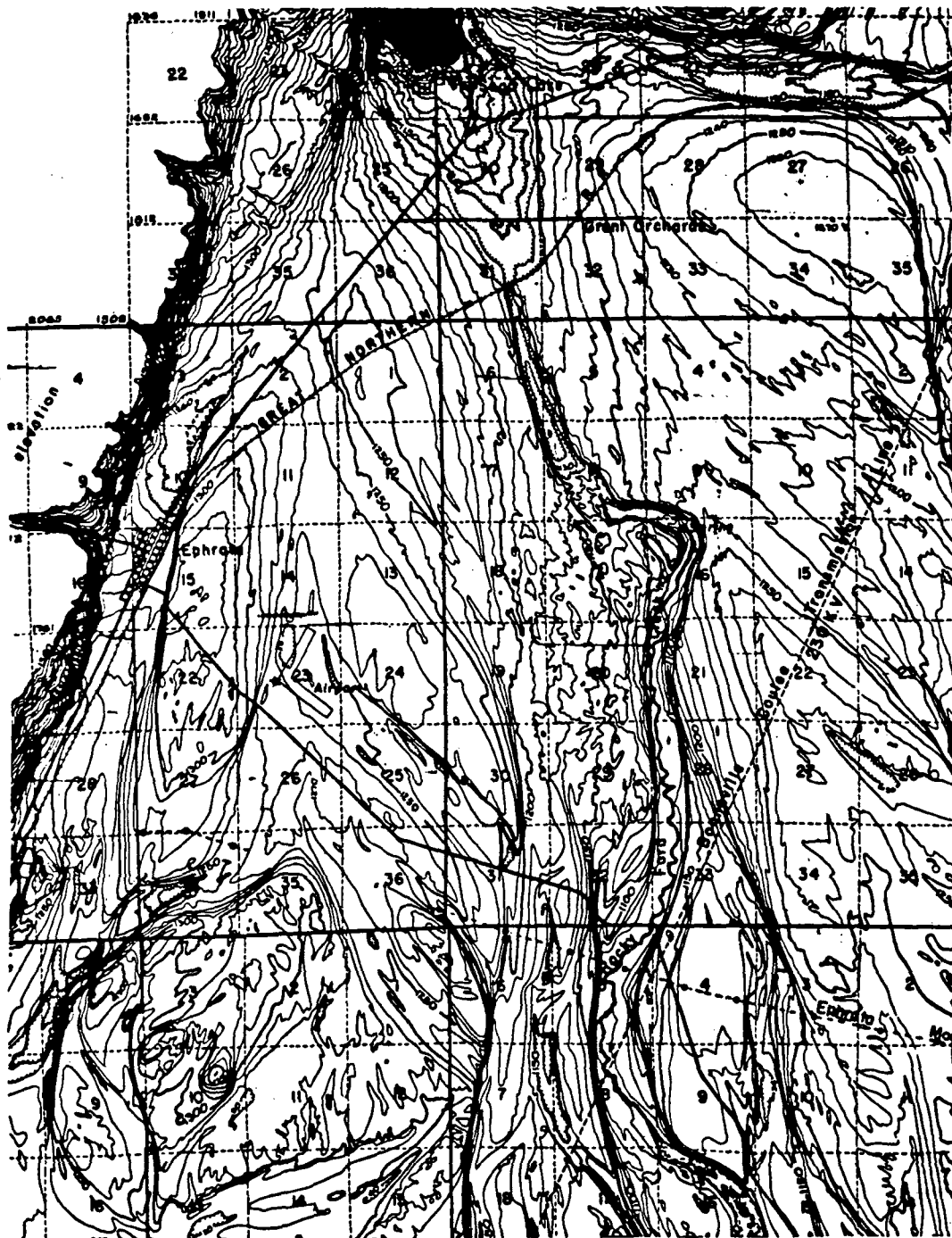
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Figure 7.29. Part of U.S. Bureau of Reclamation topographic map of the Columbia Basin Project. Contour interval is 10 feet. Note the large linear bar to the east of Ephrata. The large diamond-shaped bar in the lower left corner is more typical of most of the gravel bars on the Ephrata Fan.
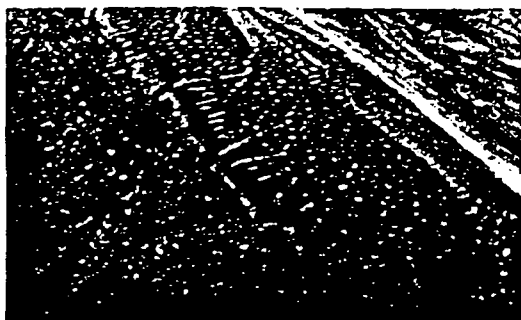
Figure 7.30. Oblique aerial view of a part of a linear gravel bar near the center of the Ephrata Fan. Flow across the bar came from the upper right to the lower left.

Figure 7.31. North-facing wall in the Columbia Concrete Products gravel pit near Ephrata. Cross-stratification dips toward the southwest. Note the concentration of large boulders at the bounding surfaces of the sets. Note man in the lower left for scale.

Figure 7.32. South-facing wall in the Columbia Concrete Products gravel pit near Ephrata. Large boulders are scattered throughout the deposit. Part of a slightly rounded basalt column is visible near the center of the photo.

cates that the Ephrata Fan was built by bar-slipface migration. The internal stratification observed in the gravel pit is consistent with this interpretation. The pit walls are characterized by thick cross-stratified sets with a dip toward the southwest (Fig. 7.31), reflecting deposition on bar slipfaces by currents flowing in a general direction from the center of the fan system across its western margin and into the Ephrata channels. Large boulders are found throughout the unit (Fig. 7.32. Most commonly, however, they are concentrated along the bounding surfaces of individual cross-stratified sets. This indicates that some scour occurred between the deposition of the individual sets, thus forming a surface armor prior to burial by a new bar slipface. The flood gravel is typically poorly sorted, with a number of broken rounds. Mud coating on the individual cobbles is ubiquitous (Fig. 7.33). The deposit is dominated by basalt fragments probably derived by erosion of the Grand Coulee. One can also find granitic rocks brought, at the very least, from the exhumed granite outcrops at the head of Grand Coulee near the present Grand Coulee Dam on the Columbia River, about 50 km to the north.

STOP 8. LENORE LAKE

The role of geologic structure in the Quaternary evolution of the Columbia Basin has been very significant (Baker, Ch. 2; Swanson and Wright, Ch. 3, this volume). Specifically, the
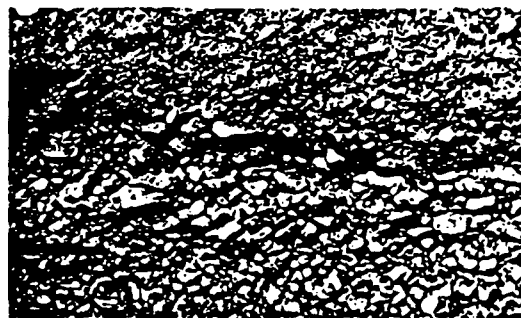

Figure 7.33. Close-up view of the open-work flood gravel in the Columbia Concrete Products pit at Ephrata. Note the mud coating.
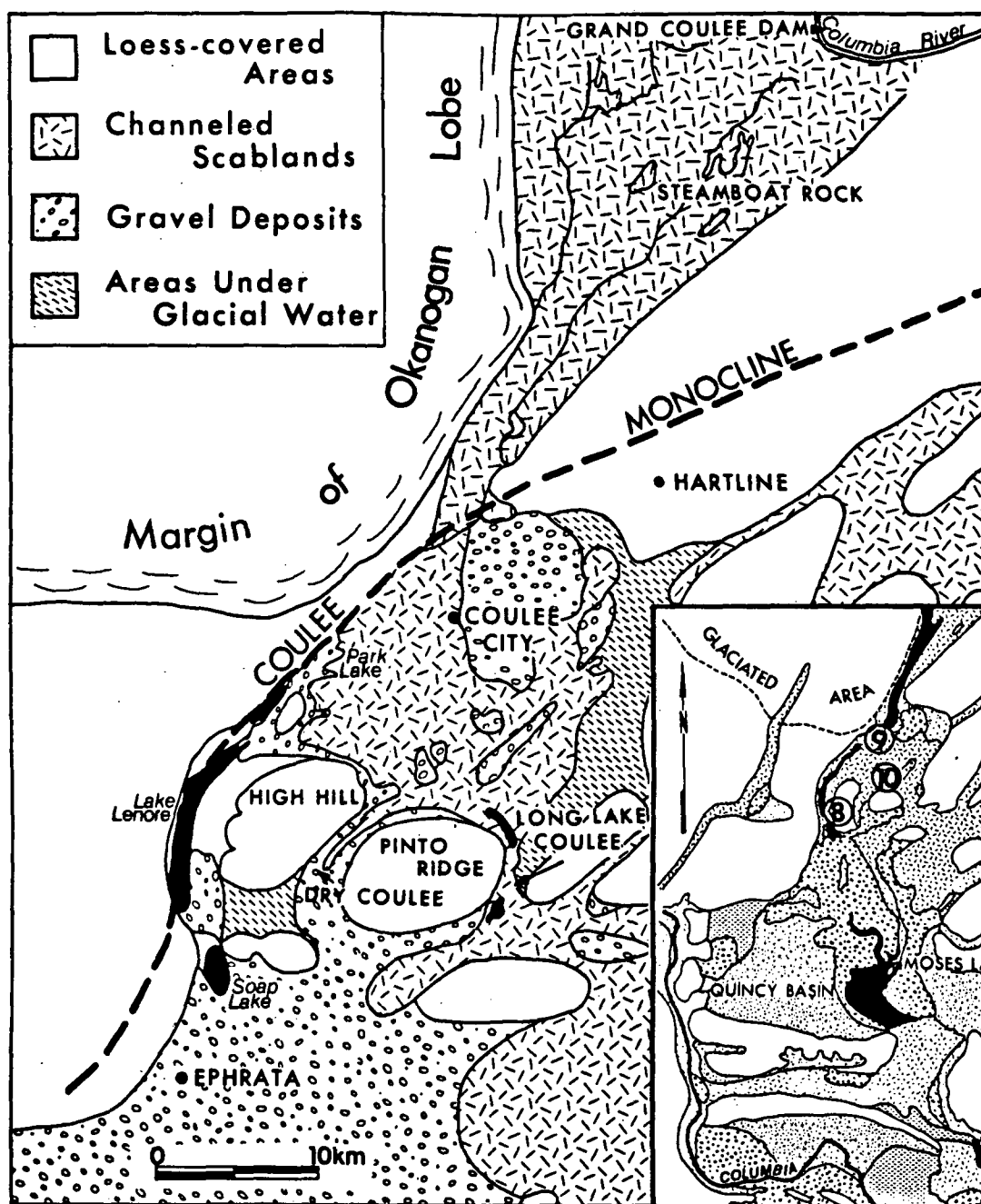
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Figure 7.34. Generalized geologic map of the Grand Coulee region. Insert shows locations of stops 8, 9 and 10. Modified from Bretz (1959, his Plate 3).

Figure 7.35. The Coulee Monocline to the north of Park Lake (see Fig. 7.37 for location). (Section of photograph 2001 by John S. Shelton.)

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shape, location and, in part, size of lower Grand Coulee is related to the existence of the Coulee Monocline, a large flexure in the Yakima Basalt trending generally southwest-northeast through the western Columbia Basin (Fig. 7.34). For about 25 km, the course of lower Grand Coulee is superimposed directly on the Coulee Monocline. The weakened rocks on the steep (45° to 60° tilt) eastward-dipping limb of the monocline yielded more readily to the erosive action of the flood than the flat-lying beds further east. Thus, the zone of maximum flood erosion moved into the weakened belt, leaving a string of lakes as a result of deep sub-fluvial plucking action (Plate 3). Deep erosion of the monoclinal limb left the lower Grand Coulee with a western wall nearly 300 meters high. Pre-flood drainage ravines which descended the monoclinal limb were left as hanging valleys high above the present valley floor giving the skyline a gabled appearance. Steeply-dipping beds of the monoclinal limb are preserved in the hogback islands of Lake Lenore and sections of the coulee wall near Park Lake (Fig. 7.35).

Through the Lenore Lake section of the Grand Coulee, one can see a particularly well-developed inner channel (Fig. 7.36). Flanking the deep, mostly lake-filled, inner channel are benches with an irregular surface topography made of basaltic knobs and potholes, a characteristic result of sub-fluvial plucking in layered volcanic rock. Baker (Chs. 4 & 5, this volume) discusses how the turbulence pattern of high-velocity flow interacts with the structure of the basalt flow to produce this diagnostic scabland morphology.

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STOP 9. DRY FALLS OVERLOOK

Dry Falls constitute the head cataract of lower Grand Coulee (Plate 3) carved by northward recession of the Lenore Canyon system. Extending from the overlook and east to Castle Lake (Fig. 7.37), this compound cataract reached a width

Figure 7.36. Oblique aerial view toward the north of Lenore Lake. Note the lake-filled inner channel and the hogback islands in the foreground.
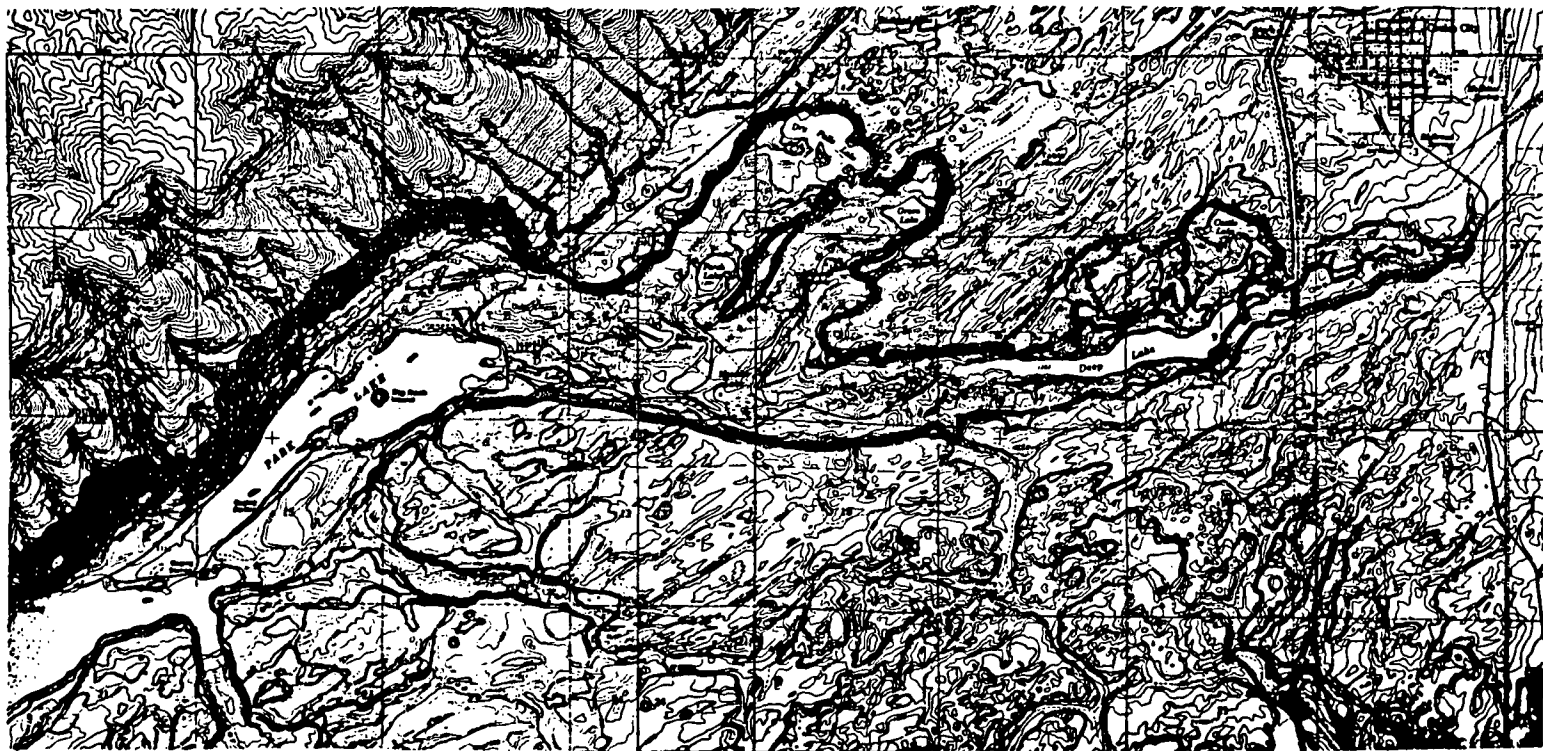

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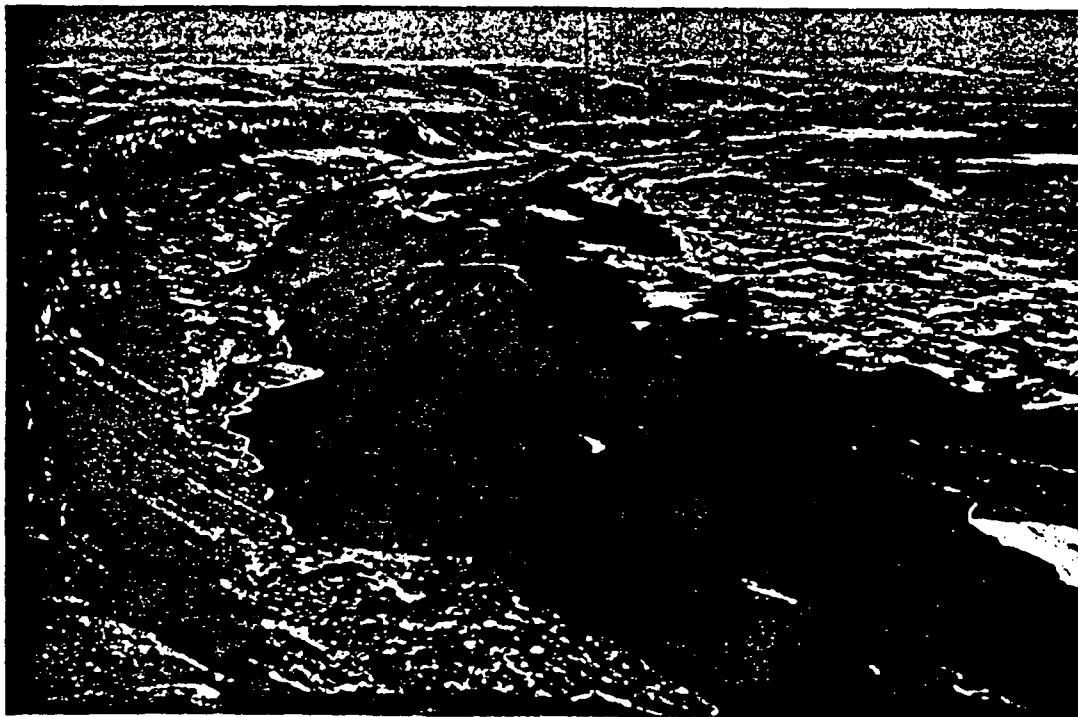
Figure 7.37. Sections of U.S. Geol. Survey topographic maps of Park Lake and Coulee City 7.5-minute quadrangles. Contour interval is 10 feet.

of nearly 6 km and a maximum height of 125 meters, substantially larger than the current Niagara Falls gorge. Bretz (1969, p. 524) points out that the cataract developed as the main thread of flood incision moved into the zone of weakened rocks along the Coulee Monocline and then was maintained as more and more of the discharge began flowing through this rapidly expanding canyon. Plunge pool lakes in alcoves at the base of the cliffs mark what appears to be the locations of discharge concentrations (Fig. 7.38). Large boulder piles can be seen immediately downstream of many of the plunge pools.

Isolated plateau remnants (e.g., Umatilla Rock, Fig. 7.39) have been left standing between more rapidly retreating recessional gorges. Highwater marks along the margin of the Hartline

Basin seem to suggest that many of the cataracts in the area might have been formed subfluvially rather than by the classical plunge pool undercutting (Baker, 1977, p. 401). This might apply to Dry Falls as well, although it is unclear whether the water depth remained adequate to maintain subfluvial recession at the time the Leonore Canyon system had been eroded to the present depth.

Immediately upstream of the cataract, as well as east of Park Lake, the scabland plateau is covered with a series of parallel longitudinal grooves ranging from 30 to 60 meters in spacing and measuring up to 3 meters in height (Figs. 7.40 and 7.41). The grooves generally parallel the flow direction and cut across any structural trends. They are formed on the resistant basalt

Figure 7.38. Oblique aerial view to the northeast of Dry Falls cateract. Coulee City is visible in the background. Large alcoves, plunge pools and boulder piles characterize the falls. Umatilla Rock, an isolated plateau remnant is visible on the right (photograph 5602 by John S. Shelton).

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Figure 7.39. Umatilla Rock, an isolated plateau remnant in the middle of the major Dry Falls cataract (for location see Fig. 7.37).
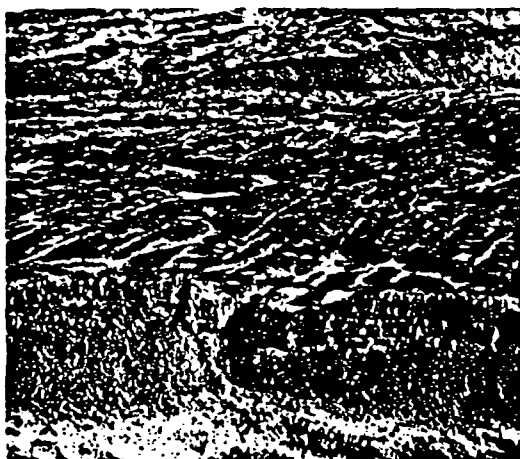

Figure 7.40. Oblique aerial view of longitudinal grooves in basalt north of Dry Falls. The grooves are spaced about 50 meters apart.

Figure 7.41. Ground view of the grooves north of Dry Falls. Note man for scale.

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entablature (Baker, 1977, p. 401) and may owe their origin to longitudinal roller vortices which are known to have formed similar grooves in laboratory experiments (Shepherd, 1972; Allen, 1971a) (Fig. 7.42). Similar grooves often are observed in swift-flowing bedrock streams under upper flow regime conditions.

Although this field trip will not visit the upper Grand Coulee (Banks Lake), its relationship to the lower Coulee should be briefly reviewed. As first proposed by Bretz (1932a), upper Grand Coulee was eroded across a previously intact divide. In contrast, lower Grand Coulee was excavated along the axis of the Coulee Monocline. The canyon system crosses the trace of the monocline a few miles north of Dry Falls (Fig. 7.34). As flood waters detoured out of the Columbia River Valley at the east margin of the Okanogan Lobe (Baker, Ch. 2, this volume), crossed the Waterville Plateau, and cascaded some 250 m down the southeast slope of the Coulee Monocline, a recessional cataract was developed which gradually migrated more than 30 kilometers across the Waterville Plateau to the south wall of the Columbia valley near the present Grand Coulee Dam (Fig. 7.34). Although the cataract ceased to exist at this point, the upper Grand Coulee continued to act as a major channel leading flood water into the Hartline Basin and lower Grand Coulee. Flow through upper Grand Coulee eroded nearly 300 meters into the pre-flood divide. Scabland surfaces on the plateau adjacent to the coulee indicate that the initial flow covered an area nearly 15 km wide at the northern side of the divide. As the cataract receded and deepened, the channel was narrowed to little more than 2 km immediately north of the Coulee Monocline, widening to about 8 km in the Steamboat Rock-Northrup Canyon area (Fig. 7.34). Between Steamboat Rock and the Columbia River, erosion exposed a series of granite knobs. Upper Grand Coulee today is filled by the Banks Lake reservoir.

STOP 10. PINTO RIDGE

The north flank of the Pinto Ridge anticline provides a good view of the complex erosional and depositional features of the Hartline Basin to the north. This broad topographic basin is
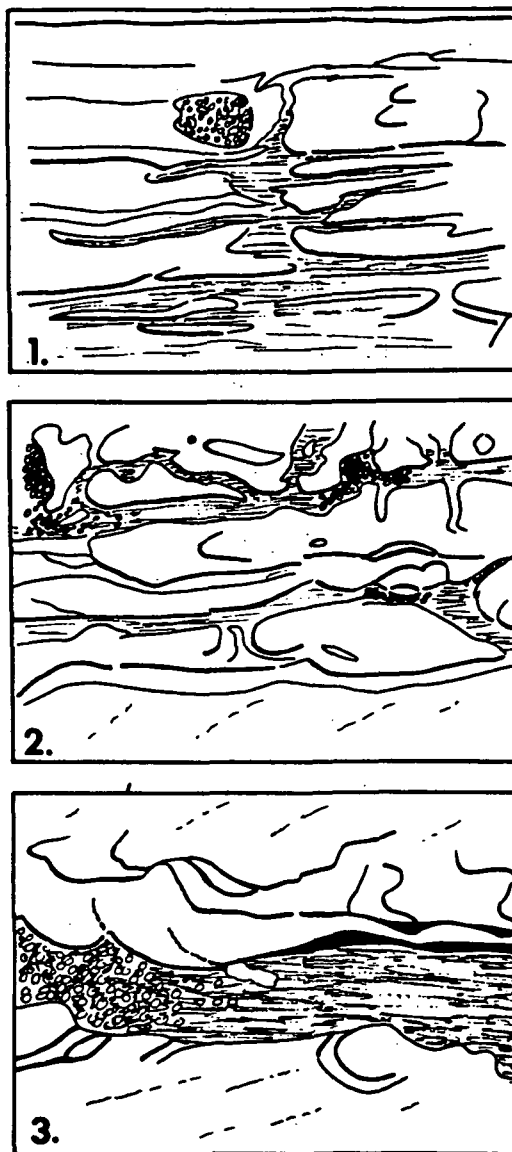

Figure 7.42. Development of experimental scour features in consolidated material through time. 1. Development of linear grooves by longitudinal vortices. 2. Groove enlargement and reduction in number by non-uniform shear stress at the bed. 3. Coalescence of grooves into single channel. Each frame measures about 30 x 40 cm. Redrawn from Shepherd and Schumm (1974, their Fig. 4).

actually a combination of two broad synclines. The Hartline Syncline is bounded by the Coulee Monocline to the north and the High Hill-Trail Lake Anticline to the south. South of the Trail Lake Anticline is the Bacon Syncline (Bretz and others, 1956, p. 968) which is in turn bordered to the south by the Pinto Ridge Anticline (Fig. 7.34).

The Hartline Basin was entered by debris-laden flood water from the upper Grand Coulee and the Almira-Wilbur Coulee to the northeast. With flow divergence into the basin, some of the sediment was dropped to form a large fill between Coulee City and the town of Hartline (Fig. 7.34 and Plate 4). Isolated gravel remnants along the eastern margins of the basin (Plate 4) reach elevations as great as 515 meters where they have buried loess deposits with a calichified upper zone. Bretz and others (1956, p. 968) argue that this elevation of flood gravel demonstrates that it was deposited before the three coulees forming the present outlets of the basin had been carved. Lowering of the general water level in the Hartline Basin subsequent to the formation of Lenore Canyon, Dry Coulee and Long Lake Coulee (Fig. 7.34) caused general erosion of the eastern basin fill leaving major remnants only north of Long Lake.

The pattern of coulee development around the north flanks of High Hill (Plate 3) and Pinto Ridge (Plate 4) suggests that as the flow diverged around these "obstacles," water simultaneously occupied all three outlets of the Hartline Basin. Bottom gradients, the narrowness of channels and the lack of backfill bars support this idea (Bretz and others, 1956, p. 969). Baker and Milton (1974) pursued the idea by suggesting that these two hills affected flow patterns of water draining from the Hartline Basin in a manner similar to that of crater "obstacles" at the mouth of Ares Vallis on Mars.

The scour crescents around the Martian craters, however, are morphologically more similar to those commonly observed around bridge piers and streambed boulders on earth. Such obstacle marks are generally attributed to horseshoe vortex patterns (Shen, 1971). In terms of scale, on the other hand, the Martian scour features correspond to the coulees around High Hill and Pinto Ridge.

The Hartline Basin and lower Grand Coulee offer perhaps the most spectacular erosional topography of the entire Channeled Scabland (Fig. 7.43). The multitude of small and large coulees, cataracts, anastomosing channels and butte-and-basin topography (Plates 3 and 4) provide an assemblage of forms which are an unlikely product of any process but that of a catastrophic flood. Complex vortices, intense turbulence and high pressure gradients are required to pluck and undermine the bedrock of the channel floors. Baker (Ch. 4, this volume) provides details of the postulated hydrodynamics responsible for this scabland topography.

STOP 11. CRAB CREEK

Crab Creek Coulee follows one of the major pre-flood east-west drainage lines across the central Columbia Basin. During the Missoula Flood, it was a major distributary from the Cheney-Palouse tract westward to the Quincy Basin (Fig. 7.1). Its discharge increased toward the west as Lake Creek, Canniwai Creek and Wilson Creek added their flows successively. Baker (1973b) has made a comparison of pre-flood and Missoula discharges of Crab Creek just upstream of the Wilson Creek junction. As seen in Plate 5, the pre-flood valley meanders are preserved in the Yakima basalt walls. The average wavelength is about 2000 meters which indicates a bankfull discharge of about 850 m^3/sec. Baker (1973a) estimated from a series of hydraulic geometry measurements that the peak discharge of the Missoula Flood was about 2.8×10^6 m^3/sec, an increase over pre-flood discharge by a factor of more than 3000!

This central part of Crab Creek displays spectacular examples of two features which provide convincing evidence of a flood origin for the Channeled Scabland: large gravel bars and giant current ripples. Along the section of Crab Creek shown in Plate 5, a series of distinct bars can be observed. Their overall topography suggests subfluvial origin. They are generally situated on the valley floor, streamlined in conformity with the bedrock valley outlines, and show an overall convex cross profile. The giant ripples further corroborate the idea. These are all asymmetric down-

stream and have steeply dipping internal cross-strata. Where Route 28 cuts longitudinally through a large bar a few kilometers west of Wilson Creek, one can see beautiful ripple cross-sections. Surface undulations are somewhat subdued due to deposition of post-flood loess, although aerial photos still clearly reveal their existence (Fig. 7.44 and 7.45). Topographic maps issued by the U.S. Bureau of Reclamation provide excellent data on the geometry of these and many other ripple fields.

The dominant geometric pattern of the Channeled Scabland seen in LANDSAT images (Ch. 8, this volume) or generalized geologic maps (Fig. 7.1) is that of large-scale channel anastomosis. The flow pattern here at Crab Creek clearly documents the origin of such geometry. The largely east-west trending pre-flood drainage ways on the plateau carried the brunt of the Missoula Flood from the Cheney-Palouse tract into the

Quincy Basin. With a discharge increase of a factor of 3000 above normal bankfull flow, however the entire valley had inadequate capacity. Flood water spilled across interfluve devides as a necessary consequence, causing the establishment of new scabland channels along the generally southwest trending tributaries of the main rivers. The coarse pattern of anastomosis, characterizing the central Channeled Scabland between the Columbia River in the north and the Snake River in the south, was generally developed by such accentuation of pre-flood drainage.

STOP 12. ROCKY FORD CREEK

The general processes responsible for the development of the Ephrata Fan were discussed at Stop 7. As indicated there, accumulations of

Figure 7.43. Oblique aerial view of Deep Lake, the easternmost cataract of the Dry Falls system (see Fig. 7.37 for location). Coulee City and the upper Hartline Basin visible in the background (photograph 5600 by John S. Shelton).

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gravel at the boundary surfaces of individual cross-stratified sets demonstrate episodes of surface scour even during the general constructional phase of fan development. The large contiguous area of boulder armor along the west side of Rocky Ford Creek (Plate 2) also indicates extensive scour, as does the fact that this surface is, on the average, 15 meters below the finer-grained fan surface to the west (Fig. 7.29). It has been suggested that this extensive scour, as well as the development of Rocky Ford Creek itself, was caused by high-velocity currents, associated with drainage of the Quincy Basin, during the waning stages of the flood (Baker, 1973a). Such a hypothesis is consistent with what is known about channel development on braided stream bars during falling river stage (Smith, 1971; Nummdal and others, 1974). There is reason to believe that the Ephrata channel system to

the west and the Willow Springs channels to the east (Fig. 7.28) owe their origin to the same basin drainage.

An indication of the current velocities attained during this phase of basin-fill incision can be gained from the pattern of scour around individual large boulders on this armor surface. A large boulder to the north of the road to the fish hatchery (Fig. 4.15) has a prominent scour crescent on its northwest (upstream) side as well as a large elliptical scour hole to the southeast (Baker, Ch. 4, this volume). This scour pattern can best be accounted for by a dual vortex system generated by this blunt obstacle to the flow. The upstream scour probably owes its origin to the flow separation caused by strong pressure gradients with the consequent development of a horseshoe vortex system. Shen (1971) suggests that this vortex system is largely responsible for
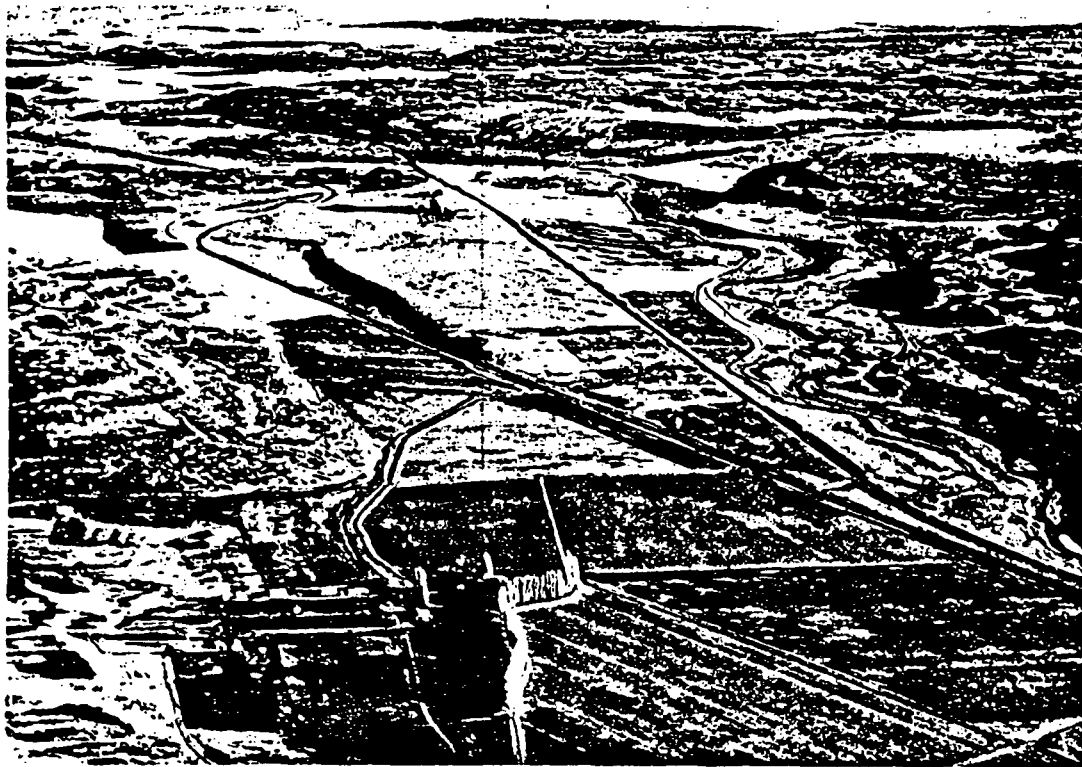

Figure 7.44. Oblique aerial view to the east along Crab Creek. The town of Wilson Creek is visible in the upper left. Washington Route 28 cuts across a large mid-coulee bar in the center of the photo exposing a series of good ripple cross-sections (photo 2052 cr by John S. Shelton. Reproduced from "Geology Illustrated" by John S. Shelton. W. H. Freeman and Company. Copyright © 1966.).

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upstream scour around bridge piers and Karcz (1968) attributes common current crescents to the same phenomenon. This author has observed large horseshoe vortex systems around stranded icebergs during a glacier burst (jökullhlaup) in Iceland.

The downstream scour is probably due to a wake-vortex system generated in the lee of the boulder. This vortex system can be either erosional or depositional depending on the flow Reynold's number. At low Reynold's number (low current velocity) deposition would most likely occur behind the obstacle. Flow at high Reynold's numbers might generate a wake-vortex capable of removing even coarse sediments (Shen, 1971). The presence of this downstream elliptical scour behind this and other boulders on the Ephrata Fan, therefore, is suggestive of rather strong currents during the drainage of the Quincy Basin (Baker, 1977, p. 407).

STOP 13. GEORGE GRAVEL PIT

The deduced implications of the stratigraphy in this western Quincy Basin are largely based on unpublished data by George Neff, summarized by Bretz and others (1956, p. 985), Bretz (1969, p. 529) and Webster and others (1976, p. 11). Gravel exposed at George records pre-Bull Lake flooding of the Columbia Basin. At least two episodes of early flooding have been recognized by Neff. This stop exposes the older of the two gravels. One of the deposits may be contemporaneous with the flood responsible for pre-Bull Lake gravels at the Marengo railroad-cut (this chapter, Stop 3), although no certain correlation between old flood gravels in the Cheney-Palouse tract and the western Channeled Scabland has yet been established (Baker, Ch. 2, this volume). The record consists of typical coarse, open-work flood gravels with foresets dipping to the south-


Figure 7.45. Oblique aerial view to the south of giant ripples at the town of Wilson Creek. Flow was from left to right.

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east, *away from* the head of the Potholes cataract to the west (Fig. 7.46). Paleoflow directions based on foresets in this rather localized exposure may not be too reliable. However, the implied south-eastward flow gains credence when regional grain size trends and lithologic characteristics of the sediments are taken into account. The exposures

contain boulders of a gray-green tuffaceous silt and sand which can only come from the Vantage standstone member of the Yakima Basalt (see Swanson and Wright, Ch. 3, this volume). The nearest outcrops are at Babcock Ridge, 10 km to the west. Also, the grain size of flood gravel decreases in an eastward direction. At Winchester Wasteway, 10 km east of George, flood debris is mostly sand and gravel with the largest cobbles only 10 cm in diameter. East of Winchester

Figure 7.46. Schematic geologic map of the western Quincy Basin and the Babcock Ridge spillways. Field stops 13, 14 and 15 are shown.
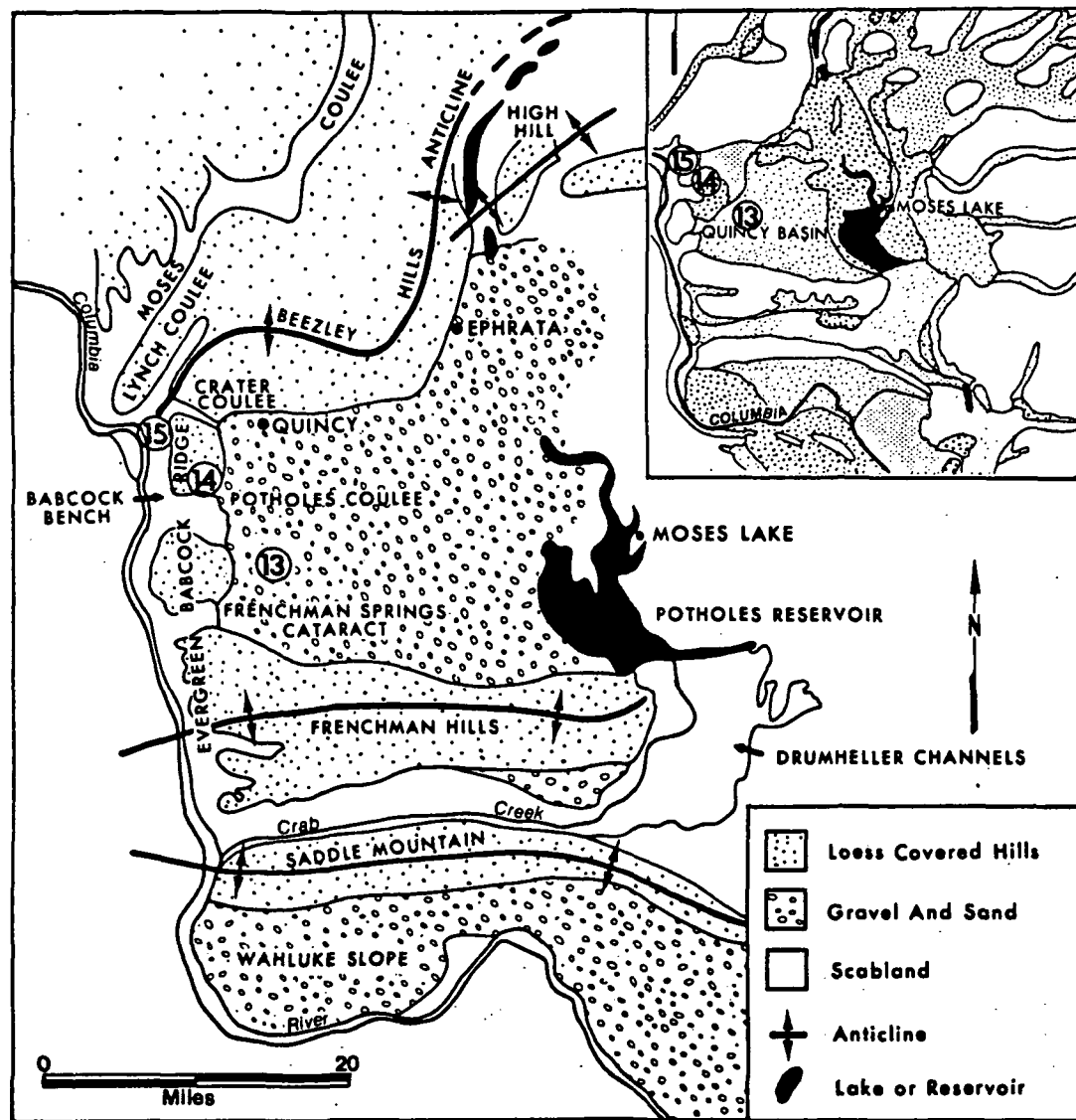
Wasteway, older flood gravel is buried by deposits of the last (early Pinedale) Missoula Flood which appear to have filled the bulk of the Quincy Basin.

The uppermost meter of gravel in the deposit at George is capped by horizontally laminated caliche. This is underlain by 30 to 50 cm of carbonate cemented gravel. Local carbonate cementation in the coarse gravel continues to a depth of 2.5 meters. Individual cobbles are carbonate-coated on their underside down to a depth of 3.5 meters. In the upper 2 meters, the weathering rind on the basalt cobbles may exceed 8 cm in thickness. Below 3 meters, however, the gravel shows no evidence of weathering. Based on this soil development, Richmond and others (1965) proposed a pre-Bull Lake age for the deposit.

STOP 14. POTHOLES COULEE

The Quincy Basin is separated from the Columbia River valley to the west by Babcock-Evergreen Ridge, which extends from the Beezley Hills in the north to the Frenchman Hills in the south. The ridge summit attains an altitude of 550 meters, about 100 meters above the average altitude of the sedimentary fill of the Quincy Basin to the east (Fig. 7.46). As the flood water rose in the Quincy Basin, it spilled across saddles in this ridge and cascaded down the east side of the Columbia River valley, the floor of which today is 300 meters below the ridge crest. The spillover created three major recessional cataracts. From the south to the north, these are: the Frenchman Coulee, Potholes Coulee and Crater Coulee (Plates 6 and 7). The latter joined Lynch Coulee before entering the Columbia River.

Bretz has repeatedly used these coulees as one of his main arguments for a flood origin of the Channeled Scabland. In addition to their large size and perpendicular orientation relative to the Columbia River, it is significant to note that each spillway begins at very nearly the same altitude (Bretz, 1959, p. 26). This fact strongly suggests that they were all contemporaneous in origin, requiring that the *entire* Quincy Basin was filled with water up to this elevation at one time. Other authors have suggested alternative ideas to make the spillways sequential in operation and thus

avoid such enormous quantities of water. The ideas include tectonic movements such that, after one cataract had formed, another part of the ridge was depressed to draw the discharging water off from one cataract to make a new one. Other ideas include large gravel fills subsequently eroded away, or strategically located ice-jams. None of these ideas has any independent supporting field evidence.

The support for the flood origin of these three coulees becomes even stronger when one considers the fact that a fourth discharge way out of the Quincy Basin, the large Drumheller Channels complex in the southeastern corner of the basin (Plate 8), also has an elevation at its upper limits equivalent to that of the coulees through the Babcock Ridge.

The largest of the Babcock Ridge cataracts, Potholes Coulee (Plate 6) is about 2 km wide, about 150 meters deep and has receded about 3 km into the ridge from the wall of the Columbia Valley above Babcock Bench (Fig. 7.46). A broad region of eroded scabland topography east of the coulee is evidence for the convergence of flood water from the Quincy Basin into the two main cataracts of the coulee. Deep plunge pools and gravel mounds make up the floor of both cataracts (Fig. 5.25). Alignment of the main cataract's head wall appears controlled by the joint pattern in the basalt (Fig. 7.47).

Along the east side of the Columbia River at the elevation of the floor of the two recessional cataracts of Potholes Coulee is Babcock Bench, a basalt scabland surface about one kilometer wide extending nearly 15 km along the river. The channel width and depth expressed by this bench is an indication of the discharge carried by this reach of the Columbia River during the Missoula Flood.

This stop provides excellent exposures for the study of the basalt and associated lithologies of the Yakima Subgroup. A typical basalt flow has a scoracious upper portion grading into the upper colonnade of relatively small and short columns. In many flows, this upper colonnade may be missing altogether. Underlying this is the entablature, consisting of long slender, often twisting and flaring columns. This upper part of the lava flow is generally the one most resistant to erosion. Underlying the entablature is the lower colonnade,

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Figure 7.47. East wall of the main cataracts at Potholes Coulee. Its alignment appears to be controlled by a major north-south trending joint. Note the deep water-filled plunge pools on the right (photo by Larry G. Ward).

made of coarse, 1 to 3 meter diameter, columns (see Fig. 5.37 and 4.14). Depending on whether the lava was emplaced in a lake, the base of the flow is often a pillow-palagonite complex (Fig. 7.48) with gas chimneys.

Between the emplacement of many of the individual basalt flows, enough time elapsed to permit weathering, erosion, the growth of forest cover, and lake formation (Swanson and Wright, Ch. 3, this volume). As a consequence, local sedimentary intercalations in the basalts include conglomerate beds, clay layers and fresh-water diatomite (Fig. 7.49). Pieces of petrified wood from the interbasalt lake beds can be found.

STOP 15. CRESCENT BAR

Crescent Bar (recreation area) is located where the flood water discharging down Crater and Lynch Coulees joined the Columbia River valley at the northern terminus of the Babcock Bench (Plate 7). Directly across the river is West Bar, a large flood-generated point bar covered with an extensive set of giant current ripples (Fig. 7.50). From Route 28 immediately north of the Crescent Bar exit, one has a good view of the surface of West Bar.

The mouth of Lynch Coulee contains evidence both relating to the (1) relative age of flooding
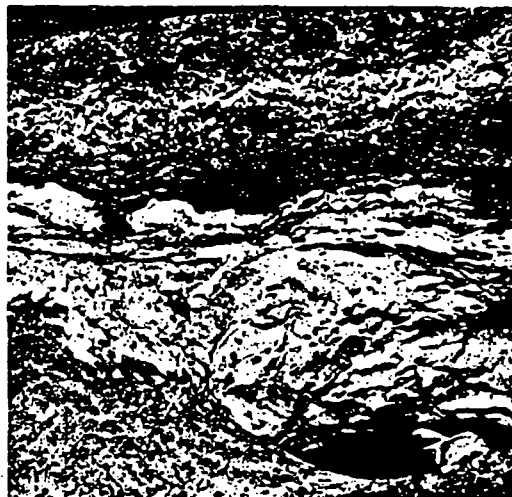

Figure 7.48. Pillow lava and palagonite overlying altered lacustrine sediments in a minor road-cut near the head of Potholes Coulee.

Figure 7.49. Interbasalt diatomite beds exposed near the head of Potholes Coulee.

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down the Columbia River Valley and the Quincy Basin and (2) concerning the absolute age of the most recent flood.

According to Waitt (1977b, p. 15), there are two gravel units exposed in Lynch Coulee upstream of the Hyw. 28 culvert. The lower gravel unit has foreset bedding dipping up the coulee. The upper unit has foresets which all dip down the coulee. There is no evidence of weathering on top of the lower gravel, suggesting that both units are of similar age if not contemporaneous. Waitt concludes that both units date from the last major Missoula Flood. The first surge of this flood carried sediment up Lynch Coulee and perhaps into the Quincy Basin; the later part of the flood carried gravel down the coulee into the Columbia Valley.

In the gravel pit east of the Crescent Bar road, there is exposed a fine pebble gravel with northward dipping foresets and an up-Columbia provenance throughout. This is interpreted by Waitt as indicative of a huge counterclockwise eddy that formed in this alcove when the main flood current flowed down-valley over West Bar (across the river).

Overlying the flood gravel are 2 meters of gravel, sand and laminated fine sand and silt diagnostic of temporary slack-water deposition, perhaps in a lake hydraulically ponded behind Wallula Gap. Near the base of the finer unit are three layers of tephra. (Waitt, 1977b, p. 15). This tephra has been interpreted as the Mount St. Helens' Set S ash (Fig. 2.16). As the tephra is equivalent to or only slightly younger than the 13,000 years B.P. for the last major Missoula Flood (Mullineaux and others, 1977). Waitt offers the tantalizing speculation that the contemporaneity of the rather short-lived flood and the Mount St. Helens eruption might imply that the weight of the flood water could have triggered the eruption.

Figure 7.50. Oblique aerial view to the south of West Bar on the Columbia River across from Lynch Coulee. Giant gravel ripples demonstrate flood-flow toward the top of the picture, i.e. down the Columbia Valley. Babcock Bench extends along the river in the upper left of the photo (photograph 5595 by John S. Shelton).

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Table 7.1. List of Geographic Coordinates of the Field Trip Stops

Stop	Map. Quad.	Latitude	Longitude	Township	Range	Sect.
1. Williams Lake	Cheney 15'	47°17'N	117°42'W	T21N	R40E	25
2. Macall	Macall 7½'	47°3'30"N	118°05'W	T18N	R38E	18
3. Marengo	Marengo 7½'	47°01'N	118°12'30"W	T18N	R37E	31
4. H U Ranch	Haas 15'	46°40'N	118°17'W	T14N	R36E	27
5. Snake/Palouse Jct.	Starbuck 15'	46°35'N	118°13'W	T13N	R37E	19/30
6. Sand dunes	Sieler 7½'	47°04'N	119°14'W	T18N	R29E	7
7. Gravel pit	Ephrata 7½'	47°18'N	119°33'W	T21N	R26E	22
8. Lenore Lake	Ephrata 15'	47°28'N	119°31'W	T23N	R26E	26
9. Dry Falls	Coulee City 7½'	47°36'N	119°21'W	T24N	R28E	6
10. Pinto Ridge	Stratford 7½'	47°30'N	119°20'W	T23N	R28E	17
11. Crab Creek	Wilson Creek 15'	47°25'N	119°06'W	T22N	R30E	7
12. Rocky Ford Creek	Grant Orchards 7½'	47°19'N	119°28'W	T21N	R27E	8
13. George	George 7½'	47°06'N	119°52'W	T19N	R24E	31
14. Potholes Coulee	Babcock Ridge 7½'	47°09'N	119°56'W	T19N	R23E	9
15. Crescent Bar	Babcock Ridge 7½'	47°12'N	119°59'W	T20N	R23E	19