Figure 1. Location map of Newberry Volcano and Paulina Lake.
Stop 2-1 Lower Paulina Creek
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.
Topographic Map
Lower Deschutes (Maupin Up River)
En route to Stop 3.3

Proceed back to Interstate 84 and 1

The Dalles. The Columbia to the south and then north
basin and crosses the Col
trends southwest across thColumbia River Basalt G
Formation, which dips dow
the city. Some recently a
ment as great as 5 cm/hr hav
The Dalles (Rosenfield, 1)
Past The Dalles, where
the west is the rising flank o
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has been etched into the hill
striped loess from the top of
Group. This trimline is at 31
southwest end of the slope:
(960 ft) at the Rowena C
Point. Small granitic erratic
(940 ft) at Crates Point.
The Columbia River G
managed by the U.S. Fore
east as the Deschutes Riv
physiographic gorge is betw
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hundred meters during the
Columbia River Basalt Grot
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Tertiary and Quaternary
Pass through Rowena Ga
Rowena (Exit 76). From he
ment of the historic Columb
The scenic highway, the fit
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1913 and 1915, largely by th
It was essential to Hill an
Lancaster that the road harn
The Gorge. It was also im
serve as a functional cros
the engineering specificati
width of 24 ft, a maximum

Figure 27. Sketch and stratigraphic column of exposure at Stop 3.2.

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Figure 7. Topographic map of the settings of Petersburg and Fairbanks divide crossings, with approximate extent of the gravel bars that were deposited as flow (arrows) spilled into the valley of Fifteenmile Creek. Topographic base from Stacker Butte and Petersburg USGS 7½' quadrangles.
plastic; few very fine roots; many very fine tuberous pores; 10 percent nodules; strongly calcareous; moderately alkaline; abrupt wavy boundary.

IIR—51 inches; basalt bedrock with a thin indurated capping.

The A horizon is loam or silt loam. The B horizon is loam or heavy loam. Depth to bedrock is 40 to 60 inches or more.

33—Maupin variant loam. A representative mapping unit is in the NW¼NE¼SW¼ section 9, T. 4 S., R. 18 E. This soil is on uplands. Slopes averages about 2 percent.

Included with this soil in mapping were areas of Maupin and Bakeoven soils. These soils make up about 10 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Capability unit Ilo-3, nonirrigated and Ilo-2, irrigated; Shrubby Rolling Hills range site.

Nansene Series

The Nansene series consists of well drained soils formed in loess on uplands. Slopes are 35 to 70 percent. Elevation is 300 to 1,500 feet. The vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 11 to 13 inches, the average annual air temperature is 48°F to 52°F, and the frost-free period is 140 to 170 days at 32°F and 170 to 200 days at 28°F.

In a representative profile the surface layer is very dark brown silt loam about 22 inches thick. The subsoil is dark brown silt loam about 10 inches thick. The upper 20 inches of the subsoil is dark brown silt loam, and the lower 10 inches is grayish brown silt loam. Basalt bedrock is at a depth of about 62 inches. The surface layer and subsoil are neutral, and the subsoil is neutral to moderately alkaline.

Permeability is moderate, and the available water capacity is 6 to 11 inches. Water-supplying capacity is 8 to 12 inches. Effective rooting depth is 40 to 60 inches or more.

These soils are used for range and wildlife habitat.

Representative profile of Nansene silt loam, 35 to 70 percent slopes, in NW¼NW¼NE¼ section 29, T. 1 N., R. 15 E.:

A1—9 to 4 inches; very dark brown (10YR 2/2) coarse silt loam, dark grayish brown (10YR 4/2) dry; weak thin platy structure to parting to weak fine granular; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; neutral; clear smooth boundary.

A2—4 to 14 inches; very dark brown (10YR 2/2) coarse silt loam, dark grayish brown (10YR 4/2) dry; weak coarse prismatic structure; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; common very fine tuberous pores; neutral; clear smooth boundary.

A3—14 to 22 inches; very dark brown (10YR 2/2) coarse silt loam, dark grayish brown (10YR 4/2) dry; weak coarse prismatic structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common fine to medium tuberous pores; neutral; gradual smooth boundary.

B2—22 to 32 inches; dark brown (10YR 3/2) coarse silt loam, dark brown (10YR 4/2) dry; weak coarse prismatic structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common very fine tuberous pores; neutral; gradual smooth boundary.

34F—Nansene silt loam, 35 to 70 percent slopes. A representative mapping unit is in the NW¼NW¼NE¼ section 29, T. 1 N., R. 15 E. This soil is in long, narrow areas and has north-facing slopes.

Included with this soil in mapping are areas of Walla Walla, Licksillet, and Wrentham soils and Rock outcrop that make up as much as 15 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability subclass VII; Steep North range site.

Pedigo Series

The Pedigo series consists of somewhat poorly drained soils formed in alluvium derived from loess and volcanic ash on bottom lands. Slopes are 0 to 3 percent. Elevation is 200 to 2,700 feet. In uncultivated areas, the vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 10 to 13 inches, the average annual air temperature is 50°F to 53°F, and the frost-free period is 130 to 180 days at 32°F and 180 to 200 days at 28°F.

In a representative profile the surface and subsurface layers are black silt loam to a depth of 40 inches. The upper 9 inches of the underlying material is very dark gray silt loam, and below this is dark grayish brown loam to a depth of 60 inches or more. The soil material in the profile is moderately alkaline to neutral.

Permeability is moderate, and the available water capacity is 10 to 11 inches. Water-supplying capacity is 9 to 13 inches. Effective rooting depth is more than 60 inches.

These soils are used for hay, pasture, dryfarmed small grain, range, and wildlife habitat.

Representative profile of Pedigo silt loam in the SE¼NW¼ section 21, T. 1 S., R. 13 E.:

A6—0 to 4 inches; black (10YR 2/1) silt loam, dark grayish brown (10YR 4/2) dry; weak fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; moderately calcareous; moderately alkaline; abrupt smooth boundary.

A1—2 to 8 inches; black (10YR 2/1) silt loam, dark grayish brown (10YR 4/2) dry; weak coarse prismatic structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common very fine tuberous pores; moderately calcareous; moderately alkaline; abrupt smooth boundary.

A2—8 to 21 inches; black (10YR 2/1) silt loam, dark grayish brown (10YR 4/2) dry; weak coarse prismatic structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common very fine tuberous pores; moderately calcareous; moderately alkaline; abrupt smooth boundary.
AC—21 to 40 inches; black (10YR 2/1) silt loam, grayish brown (10YR 5/2) dry; massive; hard, friable, slightly sticky and slightly plastic; many very fine roots; many fine tubular pores; neutral; clear smooth boundary.

C1—40 to 49 inches; very dark gray (10YR 3/1) silt loam, light brownish gray (10YR 5/2) dry; massive; hard, friable, slightly sticky and slightly plastic; few roots; many fine and few medium tubular pores; neutral; clear smooth boundary.

C2—49 to 60 inches; dark grayish brown (10YR 4/2) loam; massive; hard, friable, slightly sticky and slightly plastic; few roots; many fine and few medium tubular pores; neutral.

The A horizon is dark grayish brown or dark brown when dry and very dark grayish brown when moist. It is silt loam, coarse silt loam, or loam and is moderately calcareous to strongly calcareous. The AC horizon is light gray, light brownish gray, or grayish brown when dry and very dark gray, very dark grayish brown, or black when moist. It is coarse silt loam, silt loam, or silty clay loam.

**35—Pedigo silt loam.** A representative mapping unit is in the SE¼NW¼ section 21, T. 1 S., R. 13 E. This soil is in long, narrow areas on alluvial bottom lands adjacent to streams. Slopes are 0 to 3 percent.

Included with this soil in mapping are areas of Hermiston, Endersby, and Tygh soils.

Runoff is slow, and the hazard of erosion is slight. Capability unit IIw-1; Alkaline Bottom range site.

**Quincy Series**

The Quincy series consists of soils formed in sandy alluvium from mixed material on bottom lands. Slopes are 0 to 3 percent. Elevation is 1,400 to 1,500 feet. In uncultivated areas, the vegetation is cottonwoods, forbs, and shrubs. The average annual precipitation is 10 to 12 inches, the average annual air temperature is 48° to 52° F, and the frost-free period is 120 to 170 days at 32° and 170 to 200 days at 28°.

In a representative profile the surface layer is very dark gray loamy fine sand about 6 inches thick. The underlying material to a depth of 35 inches is very dark grayish brown sand, the next 9 inches is dark gray fine sand, and below this to a depth of 60 inches or more is dark gray very fine sand. The surface layer is medium acid, and the underlying material is slightly acid to neutral.

Permeability is rapid, and the available water capacity is 3 to 6 inches. Water-supplying capacity is variable and depends upon the depth to the water table. Effective rooting depth is 40 to 60 inches.

This soil is used for irrigated hay and pasture, crops, range, and wildlife habitat.

Representative profile of Quincy loamy fine sand, wet, in the NW¼SW¼NW¼ section 12, T. 4 S., R. 13 E.:

Ap—0 to 6 inches; very dark gray (10YR 3/1) loamy fine sand, gray (10YR 5/1) dry; weak fine granular structure; soft, very friable, nonsticky and nonplastic; many very fine roots; many very fine irregular pores; medium acid; clear smooth boundary.

C1—6 to 41 inches; very dark grayish brown (10YR 3/2) sand, grayish brown (10YR 5/2) dry; single grained; loose; many very fine roots; 10 percent very fine pebbles; slightly acid; clear wavy boundary.

C2—41 to 50 inches; dark gray (10YR 4/1) fine sand, gray (10YR 5/1) dry; single grained; loose; common fine roots; common dark brown (5YR 4/4) moist, mottles; slightly acid; clear wavy boundary.

C3—50 to 60 inches; dark gray (10YR 4/1) very fine sand, gray (10YR 6/1) dry; single grained; loose; very few roots; neutral.

The A horizon is gray or grayish brown when dry and very dark gray or very dark grayish brown when moist. It is loamy fine sand or loamy sand and is as much as 20 percent coarse fragments 2 to 10 millimeters in size. The C1 horizon is gray to grayish brown when dry. It is loamy sand or sand and is 10 to 20 percent pebbles. The C2 horizon is gray or light gray when dry and has common to many dark brown mottles. It is sand or very fine sand.

Quincy soils are excessively drained or somewhat excessively drained. However, this Quincy soil is on bottom land and remains wetter throughout the year than is normal for the Quincy series because of a water table at a depth of 40 to 60 inches.

**36—Quincy loamy fine sand, wet.** A representative mapping unit is in the NW¼SW¼NW¼ section 12, T. 4 S., R. 13 E. This soil is on bottom lands along major streams. Slopes are 0 to 3 percent.

Included with this soil in mapping were areas of Endersby, Tygh, and Pedigo soils. These soils make up as much as 10 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Depth to a water table is 40 to 60 inches in spring and early in summer. Some areas are subject to overflow. Capability unit IIIw-1; Semi-Moist Bottom range site.

**Riverwash**

**37—Riverwash.** A representative mapping unit is in the NE¼SW¼NW¼ section 11, T. 4 S., R. 13 E. Riverwash is in narrow, irregularly shaped strips in the bends of stream channels along the Columbia and Deschutes Rivers and along drainageways in the survey area. It is 2 to 10 feet above the normal waterline. The strips are 40 to 200 yards wide. Riverwash consists of well-rounded sand, gravel, stones and boulders, chiefly basalt. The surface layer generally is uneven. This area has little or no vegetation.

Riverwash is subject to overflow when the water is high and is extremely dry when the water is low. During each overflow, new deposits are received and some material is removed. Adjacent river sandbars are included in the unit.

Riverwash is used for wildlife habitat and as a source of sand and gravel. Capability subclass VIIIw; not placed in a range site.

**Rock Outcrop**

**38—Rock outcrop-Rubble land complex.** A representative mapping unit is in the NW¼NE¼ section 17, T. 3 S., R. 15 E. This complex is about 65 to 75 percent Rock outcrop and 20 to 30 percent Rubble land. It is on uplands in basalt outcrop and rubble (fig. 5). Elevation is 200 to 3,600 feet. Rock outcrop-Rubble land complex has little or no vegetation except on included soils. The average annual precipitation is 10 to 22 inches, the average annual air temperature is 45° to 52° F, and the frost-free period is 70 to 210 days.
and slightly plastic; many very fine roots; many very fine irregular pores; slightly acidic; abrupt smooth boundary.

A1—2 to 5 inches; dark brown (10YR 3/3) loam, brown (10YR 5/3) dry; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; common very fine tubular pores; slightly acid; clear smooth boundary.

B1—11 to 21 inches; dark brown (10YR 3/3) loam, grayish brown (10YR 5/3) dry; weak medium subangular blocky structure; hard, friable, slightly sticky and slightly plastic; common very fine roots; many very fine tubular pores; slightly acid; clear smooth boundary.

B2—21 to 33 inches; dark brown (10YR 3/3) heavy loam, brown (10YR 6/3) dry; moderate medium subangular blocky structure; very hard, friable, slightly sticky and slightly plastic; few very fine roots; many very fine tubular pores; few thin clay films on ped faces and common moderately thick clay films in pores; many gray (10YR 7/2) sand coatings on peds; slightly acid; gradual smooth boundary.

B2a—33 to 49 inches; brown (10YR 3/3) clay loam, pale brown (10YR 6/3) dry; moderate medium subangular blocky structure; very hard, firm, sticky and slightly plastic; few very fine roots; many very fine tubular pores; few thin clay films on ped faces and common thin clay films in pores; many gray (10YR 7/2) sand coatings on peds; neutral; gradual smooth boundary.

C—49 to 60 inches; dark brown (10YR 4/3) loam, pale brown (10YR 6/3) dry; massive; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine tubular pores; neutral.

The A horizon is grayish brown or brown when dry and very dark grayish brown or dark brown when moist. It is very fine sandy loam, fine sandy loam, or loam. The B2 horizon is light brownish gray, pale brown, brown, or yellowish brown when dry and dark brown, dark yellowish brown, or grayish brown when moist. It is clay loam, sandy clay loam, or heavy loam and is 22 to 35 percent clay.

45B—Van Horn loam, 0 to 8 percent slopes. A representative mapping unit is in the NW1/4 SE1/4 NW1/4 section 7, T. 2 N., R. 12 E. This soil is in broad, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth, Cherryhill, and Wind River soils. These soils make up about 10 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Capability unit I1e-1; Pine-Oak-Fescue range site.

45C—Van Horn loam, 8 to 12 percent slopes. A representative mapping unit is in the NE1/4 SW1/4 NW1/4 section 18, T. 2 N., R. 11 E. This soil is in broad, irregularly shaped areas. It has the profile described as representative of the series.

Included with this soil in mapping were areas of Chenoweth, Cherryhill, and Wind River soils. These soils make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit I1e-2; Pine-Oak-Fescue range site.

45D—Van Horn loam, 12 to 20 percent slopes. A representative mapping unit is in the NW1/4NW1/4 NW1/4 section 7, T. 2 N., R. 12 E. This soil is in long, narrow, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth, Cherryhill, and Wind River soils. These soils make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit I1e-2; Pine-Oak-Fescue range site.

45E—Van Horn loam, 20 to 35 percent slopes. A representative mapping unit is in the SE1/4SE1/4SW1/4 section 6, T. 2 N., R. 12 E. This soil is in narrow, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth, Cherryhill, and Wind River soils. These soils make up about 10 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability unit IVe-1; Pine-Oak-Fescue range site.

Walla Walla Series

The Walla Walla series consists of well drained soils formed in loess on uplands. Slopes are 3 to 50 percent. Elevation is 300 to 2,000 feet. In uncultivated areas, the vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 12 to 14 inches, the average annual air temperature is 49° to 52° F, and the frost-free period is 150 to 170 days at 32° and 170 to 210 days at 28°.

In a representative profile the surface layer is very dark brown silt loam about 12 inches thick. The subsoil is dark brown and brown silt loam about 18 inches thick. The substratum is dark yellowish brown silt loam to a depth of 82 inches or more. The surface layer is slightly acid and neutral, the subsoil is neutral, and the substratum is neutral and mildly alkaline.

Permeability is moderate, and the available water capacity is 7 to 12 inches. Water-supplying capacity is 8 to 12 inches. Effective rooting depth is 40 to 60 inches or more.

These soils are used for dry-farmed small grain, hay, pasture, range, and wildlife habitat.

Representative profile of Walla Walla silt loam, 12 to 20 percent north slopes, about 600 feet north of the line between sections 12 and 13 in the SE1/4SW1/4 section 12, T. 1 N., R. 14 E.:

Ap—0 to 7 inches; very dark brown (10YR 2/3) silt loam, dark grayish brown (10YR 4/2) dry; weak thin platy structure parting to very fine granular; soft to slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; slightly acid; abrupt smooth boundary.

A1—7 to 12 inches; very dark brown (10YR 2/2) silt loam, grayish brown (10YR 5/2) dry; weak medium platy structure parting to very fine granular; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; slightly acid; abrupt smooth boundary.

B1—13 to 20 inches; dark brown (10YR 3/3) silt loam, brown (10YR 5/3) dry; weak coarse prismatic structure parting to very fine medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine pores; neutral; clear smooth boundary.

B2—20 to 31 inches; brown (10YR 4/3) silt loam, brown (10YR 5/3) dry; weak coarse prismatic structure parting to very fine medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many very fine tubular pores; neutral; gradual smooth boundary.

C1—31 to 44 inches; dark yellowish brown (10YR 3/4) silt loam, pale brown (10YR 6/3) dry; massive;
slightly hard, very friable, slightly sticky and slightly plastic; many very fine roots; many fine tubular pores; neutral; gradual smooth boundary.

C1—44 to 82 inches; dark yellowish brown (10YR 3/4) silt loam, pale brown (10YR 6/3) dry; massive; slightly hard, very friable, slightly sticky and slightly plastic; common very fine roots; many very fine tubular pores; mildly alkaline.

The A horizon is dark grayish brown, grayish brown, or brown when dry and very dark brown, very dark grayish brown, or dark brown when moist. It is silt loam or coarse silt loam. The B horizon is silt loam or coarse silt loam. The C horizon is light brownish gray or pale brown when dry and dark yellowish brown or brown when moist. It is silt loam or coarse silt loam. Lime in mycelium form is below a depth of 55 inches in some places. Depth to bedrock is 40 to more than 60 inches.

46B—Walla Walla silt loam, 3 to 7 percent slopes. A representative mapping unit is in the SW1/4SW1/4SW1/4 section 2, T. 1 N., R. 15 E. This soil is on ridgetops in broad, smooth, convex areas.

Included with this soil in mapping were areas of Anderly and Nansene soils. These soils make up about 5 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Capability unit 1Ie-3; Rolling Hills range site.

46C—Walla Walla silt loam, 7 to 12 percent slopes. A representative mapping unit is in the SW1/4SW1/4SW1/4 section 3, T. 1 N., R. 15 S. This soil is on ridgetops in broad, smooth, convex areas.

Included with this soil in mapping were areas of Anderly and Nansene soils. These soils make up about 5 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit 1Ile-1; Rolling Hills range site.

46D—Walla Walla silt loam, 12 to 20 percent north slopes. A representative mapping unit is in the SE1/4 SW1/4SW1/4 section 12, T. 1 N., R. 14 E. This soil is in long, broad, convex areas. It has the profile described as representative of the series.

Included with this soil in mapping were areas of Anderly and Nansene soils. These soils make up about 5 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit 1Ile-4; Droughty North Exposure range site.

47D—Walla Walla silt loam, 12 to 20 percent south slopes. A representative mapping unit is in the SW1/4 SW1/4SW1/4 section 6, T. 1 N., R. 15 E. This soil is in long, broad, convex areas.

Included with this soil in mapping were areas of Anderly and Nansene soils that make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit 1Ile-4; Rolling Hills range site.

47E—Walla Walla silt loam, 20 to 35 percent north slopes. A representative mapping unit is in the NE1/4 SW1/4SW1/4 section 9, T. 1 N., R. 14 E. This soil is in long, broad, irregularly shaped areas.

Included with this soil in mapping were areas of Anderly and Nansene soils that make up about 10 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability unit 1Ve-3; North Exposure range site.

48E—Walla Walla silt loam, 20 to 35 percent south slopes. A representative mapping unit is in the NW1/4 NW1/4NW1/4 section 10, T. 1 N., R. 14 E. This soil is in long, broad, irregularly shaped areas.

Included with this soil in mapping were areas of Anderly and Nansene soils that make up about 10 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability unit 1Ve-2; Droughty South Exposure range site.

48F—Walla Walla silt loam, 35 to 50 percent south slopes. A representative mapping unit is in the SW1/4 SE1/4NE1/4 section 7, T. 1 N., R. 14 E. This soil is in long, narrow, irregularly shaped areas.

Included with this soil in mapping were areas of Anderly and Nansene soils that make up about 10 percent of this mapping unit.

Runoff is rapid, and the hazard of erosion is severe. Capability subclass 1Ve; Droughty South Exposure range site.

Wamic Series

The Wamic series consists of well drained soils formed in volcanic ash, and loess overlying alluvium or colluvium weathered from basalt or andesite on uplands. Slopes are 1 to 70 percent. Elevation is 1,000 to 3,600 feet. In uncultivated areas, the vegetation is ponderosa pine, Douglas-fir, oak forbs, and shrubs. The average annual precipitation is 14 to 20 inches, the average annual air temperature is 46° to 50° F., and the frost-free period is 100 to 150 days at 32° and 150 to 200 days at 28°.

In a representative profile the surface layer is very dark grayish brown loam about 7 inches thick. The subsoil is dark brown loam about 21 inches thick. The substratum is dark brown heavy loam 16 or more inches thick. The soil material throughout the profile is neutral.

Permeability is moderately slow, and the available water capacity is 6.5 to 11 inches. Water-supplying capacity is 8 to 12.5 inches. Effective rooting depth is 40 to 60 inches or more.

These soils are used for dryfarmed small grain, hay, pasture, range, timber, and wildlife habitat.

Representative profile of Wamic loam, 5 to 12 percent south slopes, 100 feet south of road in the NE1/4 NW1/4NW1/4 section 26, T. 2 S., R. 12 E.: Ap—0 to 7 inches; very dark grayish brown (10YR 3/2) loam, light brownish gray (10YR 6/2) dry; weak fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; neutral; abrupt smooth boundary.

B1—7 to 18 inches; dark brown (10YR 3/3) loam, light brownish gray (10YR 6/2) dry; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine tubular pores; neutral; clear wavy boundary.

B2—18 to 28 inches; dark brown (10YR 4/3) loam, light brownish gray (10YR 6/2) dry; weak medium subangular blocky structure; hard, friable, slightly sticky and slightly plastic; common very fine roots; many
Bakeoven, Maupin, and Wamic soils. These soils make up as much as 15 percent of the unit. Runoff is slow, and the hazard of erosion is slight. Capability unit Ile-3 nonirrigated, and Ile-2 irrigated; Shrubby Rolling Hills range site.

54C—Watama-Wapinitia silt loams, 5 to 12 percent slopes. A representative mapping unit is in the NW1/4 SW1/4 SE1/4 section 3, T. 5 S., R. 12 E. This complex is about 55 to 65 percent a Watama silt loam and 25 to 30 percent a Wapinitia silt loam. These soils are on ridgetops in long, broad or narrow areas.

Included with this complex in mapping were areas of Bakeoven, Maupin, and Wamic soils. These soils make up as much as 15 percent of the unit. Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-4; Shrubby Rolling Hills range site.

54D—Watama-Wapinitia silt loams, 12 to 20 percent slopes. A representative mapping unit is in the SE1/4 SW1/4 section 3, T. 5 S., R. 12 E. This complex is about 55 to 65 percent a Watama silt loam and 25 to 35 percent a Wapinitia silt loam. These soils are in long, narrow, irregularly shaped areas.

Included with this complex in mapping were areas of Bakeoven, Maupin, and Wamic soils. These soils make up as much as 15 percent of the unit. Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-4; Shrubby Rolling Hills range site.

54E—Watama-Wapinitia silt loams, 20 to 35 percent slopes. A representative mapping unit is in the NW1/4 NE1/4 NW1/4 section 3, T. 5 S., R. 12 E. This complex is about 55 to 65 percent a Watama silt loam and 25 to 35 percent a Wapinitia silt loam. These soils are in long, narrow, irregularly shaped areas.

Included with this complex in mapping were areas of Bakeoven, Maupin, and Wamic soils. These soils make up as much as 15 percent of the unit. Runoff is rapid, and the hazard of erosion is severe. Capability unit IVe-2; North Exposure range site.

Wato Series

The Wato series consists of well drained soils formed in loess on uplands. Slopes are 3 to 35 percent. Elevation is 300 to 1,500 feet. In uncultivated areas, the vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 12 to 14 inches. The average annual air temperature is 51° to 54° F, and the frost-free period is 150 to 170 days at 32° and 170 to 210 days at 28°.

In a representative profile the surface layer is very dark grayish brown very fine sandy loam about 15 inches thick. The subsoil is dark brown loam about 27 inches thick. The substratum is dark brown fine sandy loam about 24 inches thick. The soil material throughout the profile is neutral.

Permeability is moderately rapid, and the available water capacity is 6 to 10 inches. Water-supplying capacity is 7 to 10 inches. Effective rooting depth is 40 to 60 inches or more.

These soils are used for dryfarmed small grain, hay, pasture, range, and wildlife habitat.

Representative profile of Wato very fine sandy loam, 3 to 7 percent slopes, 150 feet west of road in the NW1/4 NE1/4 NW1/4 section 32, T. 2 N., R. 14 E.:

A11—0 to 3 inches; very dark grayish brown (10YR 3/2) very fine sandy loam, dark grayish brown (10YR 4/2) dry; moderate medium platy structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; neutral; clear smooth boundary.

A12—3 to 15 inches; very dark grayish brown (10YR 3/2) very fine sandy loam, dark grayish brown (10YR 4/2) dry; weak coarse prismatic structure parting to weak medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular pores; 2 percent fragments 1 to 2 millimeters in size; neutral; clear smooth boundary.

B1—15 to 21 inches; dark brown (10YR 3/2) loam, brown (10YR 4/3) dry; weak medium prismatic structure parting to weak medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine irregular and tubular pores; 2 percent fragments 1 to 2 millimeters in size; neutral; clear wavy boundary.

B2—21 to 42 inches; dark brown (10YR 5/3) loam, brown (10YR 5/3) dry; weak medium prismatic and weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine tubular pores; 3 percent fragments 1 to 2 millimeters in size; neutral; clear smooth boundary.

C1—42 to 62 inches; dark brown (10YR 4/3) fine sandy loam, pale brown (10YR 6/3) dry; massive; slightly hard, friable, slightly sticky and slightly plastic; many common very fine roots; many very fine tubular pores; 5 percent weathered fragments 1 to 2 millimeters in size; neutral; clear wavy boundary.

C2—62 to 86 inches; dark brown (10YR 4/3) fine sandy loam, pale brown (10YR 6/3) dry; massive; slightly hard, friable, slightly sticky and nonplastic; few very fine roots; 10 percent weathered fragments 1 to 2 millimeters in size; neutral; abrupt wavy boundary.

The B horizon is dark brown to brown when dry. It is very fine sandy loam to loam.

55B—Wato very fine sandy loam, 3 to 7 percent slopes. A representative mapping unit is in the NW1/4 NE1/4 NW1/4 section 32, T. 2 N., R. 14 E. This soil is on ridgetops in broad, irregularly shaped areas. It has the profile described as representative of the series.

Included with this soil in mapping were areas of Lickskillet, Walla Walla, Anderly, and Nansene soils. These soils make up about 5 percent of the unit.

Runoff is slow. The hazard of water erosion is slight or moderate, and the hazard of soil blowing is moderate. Some areas are moderately eroded and have lower crop yields than noneroded areas. Capability unit IIIe-6; Rolling Hills range site.

55C—Wato very fine sandy loam, 7 to 12 percent slopes. A representative mapping unit is in the SW1/4 NE1/4 section 3, T. 2 N., R. 14 E. This soil is on ridgetops in broad, smooth, convex areas.

Included with this soil in mapping were areas of Lickskillet, Walla Walla, Anderly, and Nansene soils. These soils make up about 10 percent of the unit.

Runoff is medium. The hazard of water erosion is moderate. Capability unit IIIe-6; Rolling Hills range site.

55D—Wato very fine sandy loam, 12 to 20 percent north slopes. A representative mapping unit is
in the NE\(\frac{3}{4}\)SE\(\frac{3}{4}\)NW\(\frac{1}{4}\) section 32, T. 2 N., R. 14 E.
This soil is in long, broad, convex areas.

Included with this soil in mapping were areas of Lickskillet, Walla Walla, Anderly, and Nansene soils. These soils make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIe-4; Droughty North Exposure range site.

55E—Wato very fine sandy loam, 20 to 35 percent north slopes. A representative mapping unit is in the NE\(\frac{3}{4}\)SE\(\frac{3}{4}\)NW\(\frac{1}{4}\) section 31, T. 2 N., R. 14 E.
This soil is in long, narrow, broad, irregularly shaped areas.

Included with this soil in mapping were areas of Lickskillet, Walla Walla, Anderly, and Nansene soils. These soils make up as much as 15 percent of the unit.

Runoff is rapid, and the hazard of erosion is severe. Capability unit IVe-3; North Exposure range site.

Wind River Series

The Wind River series consists of well drained soils formed in old alluvium on uplands. Slopes are 0 to 30 percent. Elevation is 200 to 800 feet. In uncultivated areas, the vegetation is Douglas-fir, ponderosa pine, Oregon white oak, forbs, and shrubs. The average annual precipitation is 20 to 30 inches, the average annual air temperature is 49° to 62° F, and the frost-free period is 150 to 180 days at 32° and 180 to 210 days at 28°.

In a representative profile the surface layer is very dark grayish brown fine sandy loam about 10 inches thick. The subsoil is dark brown fine sandy loam about 34 inches thick. The substratum is dark yellowish brown sandy loam to a depth of 60 inches or more. Depth to bedrock is more than 60 inches. The soil material in the profile ranges from medium acid to neutral.

Permeability is moderately rapid, and the available water capacity is 7 to 8 inches. Water-supplying capacity is 10 to 14 inches. Effective rooting depth is more than 60 inches.

These soils are used for fruit orchards, pasture, range, and wildlife habitat.

Representative profile of Wind River fine sandy loam, 0 to 8 percent slopes, 400 feet north of Old Columbia River Highway in the NW\(\frac{3}{4}\)SE\(\frac{3}{4}\)NW\(\frac{1}{4}\) section 6, T. 2 N., R. 12 E.: 

Ap1—0 to 6 inches; very dark grayish brown (10YR 3/2) fine sandy loam, brown (10YR 5/3) dry; weak fine granular structure; slightly hard, very friable, non-sticky and nonplastic; many very fine roots; many very fine irregular pores; medium acid; abrupt smooth boundary.

Ap2—6 to 10 inches, very dark grayish brown (10YR 3/2) fine sandy loam, brown (10YR 6/3) dry; weak medium subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; many very fine roots; many very fine irregular and tubular pores; slightly acid; gradual smooth boundary.

B2—10 to 17 inches; dark brown (7.5YR 3/3) fine sandy loam, brown (10YR 5/3) dry; weak medium subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; many very fine roots; few fine tubular pores; neutral; gradual smooth boundary.

B3—17 to 44 inches; dark brown (7.5YR 3/4) fine sandy loam, brown (10YR 5/4) dry; weak medium subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; common very fine roots; many very fine tubular pores; few 1 to 5 centimeter nodules; neutral; gradual smooth boundary.

C1—44 to 61 inches; dark yellowish brown (10YR 4/4) sandy loam, brown (10YR 5/4) dry; massive, slightly hard, friable, nonsticking and nonplastic; common very fine roots; neutral; clear wavy boundary.

The A horizon is brown, grayish brown, or dark grayish brown when dry and very dark grayish brown, very dark brown, or dark brown moist. It is fine sandy loam or sandy loam. The B horizon is brown, grayish brown, or dark grayish brown when dry and very dark grayish brown, very dark brown, or dark brown moist. It is fine sandy loam, loam, or sandy loam. It has weak coarse prismatic or weak coarse or medium subangular blocky structure. The C horizon is yellowish brown, brown, or light yellowish brown when dry and dark yellowish brown or brown moist. It is fine sandy loam, sandy loam, loamy fine sand, or sand and is 0 to 20 percent rock fragments 2 to 5 millimeters in diameter.

56B—Wind River fine sandy loam, 0 to 8 percent slopes. A representative mapping unit is in the NW\(\frac{3}{4}\)SE\(\frac{3}{4}\)NW\(\frac{1}{4}\) section 6, T. 2 N., R. 12 E. This soil is on ridgetops in broad, irregularly shaped areas. It has the profile described as representative of the series.

Included with this soil in mapping were areas of Chenoweth and Van Horn soils. These soils make up about 10 percent of the unit.

Runoff is slow, and the hazard of erosion is slight. Capability unit IIe-1; Pine-Oak-Fescue range site.

56C—Wind River fine sandy loam, 0 to 12 percent slopes. A representative mapping unit is in the NE\(\frac{3}{4}\)NE\(\frac{3}{4}\)NW\(\frac{1}{4}\) section 6, T. 2 N., R. 12 E. This soil is on ridgetops in broad, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth and Van Horn soils. These soils make up about 10 percent of the unit.

Runoff is medium, and the hazard of erosion is moderate. Capability unit IIIe-2; Pine-Oak-Fescue range site.

56D—Wind River fine sandy loam, 12 to 30 percent slopes. A representative mapping unit is in the SE\(\frac{3}{4}\)SE\(\frac{3}{4}\)SE\(\frac{3}{4}\) section 1, T. 2 N., R. 11 E. This soil is in long, narrow, irregularly shaped areas.

Included with this soil in mapping were areas of Chenoweth and Van Horn soils. These soils make up about 10 percent of the unit.

Runoff is medium to rapid, and the hazard of erosion is moderate to severe. Capability unit IVe-1; Pine-Oak-Fescue range site.

Wrentham Series

The Wrentham series consists of well drained soils formed in loess and basaltic colluvium on uplands. Slopes are 35 to 70 percent. Elevation is 1,500 to 3,600 feet. The vegetation is bunchgrasses, forbs, and shrubs. The average annual precipitation is 10 to 13 inches, the average annual air temperature is 45° to 52° F, and the frost-free period is 60 to 100 days at 32° and 100 to 150 days at 28°.

In a representative profile the surface layer is very dark brown silt loam about 18 inches thick. The upper
Figure 14. Topographic setting and approximate distribution of Missoula flood deposits southeast of Arlington. The delta bars were mainly deposited by flow spilling into Alkali Canyon from the two upland channels to the east. There was substantial flow over the entire upland surface, however, as evidenced by the large gravel bar deposited on the upland surface that is depicted on the north part of the map. Topographic base from Arlington USGS 7.5' quadrangle. Land sections (numbered) are 1 mi (1.6 km) across.

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in the Gorge.

exposures of eddy deposits northwest and situate River from Liyle, near the 513-ft benchmark, vernal floods achieved stages of 180 m (600 ft). In exposure in the gravel pit north of the bench mark, it seven sets of east-dipping foresets of granule sand. These sets of foresets are capped by pebbly silty matrices. We interpret these silty-gravel horizons of base deposition between separate Mississippian of the forest sets are unconformably overlain 25 cm of steeply dipping foresets that may be scree deposited near gravel deposit is apparently slightly higher (to altitude of 195 m) and standing to the north (Figure 3) represents an older and larger maximum discharge required to inundate 180 m (590 ft) is about 4 million cubic meters indicating that there have been a lot of water passing that discharge, with was perhaps substantially larger. In which we stand at an elevation of about 70 m (520 ft), about 25 cm lower than maximum The Dales.

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at on the historic highway, pass- ing and Fairbanks, flow spilling between the Columbia River and the surface of the delta composition yielding foresets of cobble-pebble sand. A discharge of at least 3.5 million cubic meters was required for flow to overtop the dike, the delta at Peter's Dike, several of the segments separated by cross-strata, which suggests evidence of multiple flows. shows at least seven such units, from the top contained a piece of native sand that yielded a radiocarbon date of 750 B.P., indicating that at least two subunits to this date were capable of tilting over this divide.

Figure 28. Topographic setting, geomorphic features, and approximate distribution of Mississippian flood deposits (outlined by heavy lines) near Lytle. Topographic base from USGS 7.5" quadrangle. Land sections (numbered) are 1 mile (1.6 km) across.
flood stage. The combination of dense vegetation and abundant
mass wasting hinder the search. It is clear that by Portland, how-
ever, the maximum water surface descended to 120 m (400 ft)
(Allison, 1935), indicating an average gradient of 0.003. Most of
the drop probably occurred near Crown Point, at the downstream
end of the Columbia River Gorge.

For several kilometers downstream of Hood River, the valley
of the Columbia River is particularly constricted, generally nar-
rower than 2 km. About 3 km downstream of Viento State Park,
the Columbia River is approached upon by the Wind River land-
slide, one of several recent or presently active landslides in the
Columbia River Gorge (Figure 29). The upper part of the Wind
River landslide moves at fast as 15 m/yr (Allen, 1984).

Downstream of the Wind River landslide, the Columbia River
valley funnels between the twin granodiorite intrusions of Shell-
rock and Wind Mountains. Shellrock Mountain, with its constant
taveling of platty rubble at a repose angle of 42°, was a major
obstacle to early road building through the Gorge. On the north
side of the river, between Wind Mountain and Wind River, a large
pendant bar was deposited in the lee of Wind Mountain as flow
expanded out of the constriction. This bar is about 2 km long and
125 m high.

Figure 30. Landslide complex near Cascade Locks. The Bonneville lands-
slide was the most recent and may have temporarily dammed the Columbia
River about 500 years ago. Topographic base is the Bonneville 15′ quadrangle.
Land sections (numbered) are 1 mi (1.6 km) across. After Minor, 1984.
DAY 7 - COLUMBIA LANSLIDE

The best examples of polished, fluted, and scoured basalt sur-

Figure 29. Lava flows and landslides in the Columbia River Gorge, emphasizing flows that may have dammed the Columbia River from Waters (1975).
ities of mountain, trout, and salmonid migration. The alteration of flow regime associated with dam operation has also impacted the salmonids, from flooding of spawning and rearing sites by reservoirs to exposure of redds by unnaturally low flows (Ligon et al., 1995).

Overfishing by commercial operators has also been implicated in salmonid decline. The commercial catch of chinook salmon peaked at 19.5 million kilograms in 1883, and then plunged from overfishing (Dietrich, 1995). Native American fishermen noted that the huge salmon runs had disappeared from Priest Rapids on the middle Columbia River by 1905 because of unregulated commercial fishing; this was more than 30 years before the first major dam on the river was completed (Dietrich, 1995). A third major impact on the salmonids of the Columbia River basin has been the timber harvest in this region of humid climate, tectonic uplift, high relief, and naturally unstable slopes. Timber harvest exacerbates slope instability, leading to mass movements that
Mexico, for which total rainfall exceeded volumes ranging between $6.5 \times 10^8$ and $4 \times 10^9$ m$^3$. The World Meteorological Organization [1986, p. 261-263] has compiled observations of maximum depth-area-duration for individual storms (Figure 2b), for which the largest measured rainfall volume resulted from a 1916 hurricane centered in Florida that delivered an average of 226 mm of rainfall over 260,000 km$^2$, for a total of $6 \times 10^{10}$ m$^3$ of water. Similarly, $4.3 \times 10^9$ m$^3$ of water was precipitated by a 1967 hurricane in Texas. The thunderstorm that produced the record 4.5-hour rainfall at Smethport, Pennsylvania, during July 17-18, 1942 (Figure 2a) had a total storm volume in excess of $2.7 \times 10^9$ m$^3$. Exceptionally large and wet hurricanes not included in the World Meteorological Organization database likely produced even more precipitation. For example, maps of total precipitation resulting from the Oct.-Nov. 1998 Hurricane Mitch in Central America (http://cindi.usgs.gov/hazard/event/mitch/mitch/atlas/hmprecip.html; May 25, 2001) indicate a total precipitation volume of about $2 \times 10^{11}$ m$^3$.

Persistent patterns of moisture delivery. Floods in larger basins more typically result from persistent precipitation-enhancing synoptic weather or climate. Precipitation is still delivered by individual storms or convective cells as described in the previous section, but the frequency, intensity, and duration of such storms can be affected by regional or global atmospheric patterns that can persist for months to decades. Such patterns include quasi-stationary trough-and-ridge patterns of upper atmospheric circulation that can promote continued atmospheric convergence over areas of $10^8$ to $10^7$ km$^2$ for several days or weeks. Such a condition over the north-central United States was the cause of the Mississippi River floods of 1973 and 1993 [Hirschboeck, 1991; 2000]. Climatic conditions of annual to decadal duration that can cause regionally enhanced precipitation include coupled atmospheric and oceanic phenomena of hemispheric or global scales such as the El Nino/Southern oscillation (ENSO) and the Pacific Decadal Oscillation (PDO; e.g. Cayan and Peterson, 1989; Dettinger and Cayan, 2000). Even longer-term climate fluctuations,
measurments. Nevertheless, we can draw some fundamental inferences from this partial list as well as from other documented large floods and paleofloods.

All known terrestrial floods with discharges greater than $5 \times 10^5$ m$^3$/s resulted from rapid release of water stored behind natural dams or within glaciers (Table 4, Figure 3). The largest known floods of the Quaternary had peak discharges of about $2 \times 10^7$ m$^3$/s and resulted from breaches of glacial-age ice dams that blocked large mid-continent drainage systems. Most of the other largest floods ever documented resulted from breaches of natural dams, including landslide dams, ice dams, releases from caldera lakes, and ice-jam floods. Only 4 of the 27 largest documented floods were primarily the result of meteorological conditions and atmospheric water sources. However, if only historic events are considered, the proportion of large meteorological floods rises to 4 of 10.

Flooding from Ice-Dammed Lakes

The largest floods in Earth history have resulted from derangement of drainage networks. During the Quaternary, interactions of continental ice sheets with marginal drainage systems have been a primary source of landscape-shaping floods. These floods include the $2 \times 10^7$ m$^3$/s Missoula Floods along the Cordilleran Ice Sheet margin [e.g. Bretz, 1923, 1969; Baker, 1973; O’Connor and Baker, 1992], giant floods along the margins of the Laurentide Ice Sheet [e.g. Keew and Lord, 1987; Lord and Keew, 1987; Thorson, 1989; Teller and Keew, 1994], and more recently discovered giant Pleistocene floods in central Asia [e.g. Baker et al., 1993; Rudoy and Baker, 1993, Rudoy, 1998]. These floods all resulted from rapid release of water impounded either in (1) preexisting river valleys dammed by ice or (2) proglacial lakes formed along isostatically
Table 1. Paleohydraulic parameters for bedrock and alluvial channelways, including cataclysmic flood channels - Chuja, Altay [Baker et al., 1993] and Missoula Flood channels [Baker, 1973].

<table>
<thead>
<tr>
<th>Flood Channel</th>
<th>Discharge Q (m^3/s)</th>
<th>Width W (km)</th>
<th>Depth D (m)</th>
<th>Slope S</th>
<th>Velocity V (ms^-1)</th>
<th>Bed Shear Stress, τ (Nm^-2)</th>
<th>Power per Unit Area, ω (Wm^-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chuja (Altay)</td>
<td>2 x 10^7</td>
<td>3</td>
<td>400</td>
<td>0.02</td>
<td>20-45</td>
<td>5 x 10^3</td>
<td>10^5-10^6</td>
</tr>
<tr>
<td>Rathdrum (Missoula)</td>
<td>2 x 10^7</td>
<td>6</td>
<td>175</td>
<td>0.01</td>
<td>25</td>
<td>1 x 10^4</td>
<td>2 x 10^5</td>
</tr>
<tr>
<td>Grand Coulee (Missoula)</td>
<td>5 x 10^6</td>
<td>1.7</td>
<td>100</td>
<td>0.01</td>
<td>30</td>
<td>1 x 10^4</td>
<td>3 x 10^5</td>
</tr>
<tr>
<td>Amazon River</td>
<td>3 x 10^5</td>
<td>2</td>
<td>60</td>
<td>1 x 10^-5</td>
<td>2</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Katherine Gorge</td>
<td>6 x 10^3</td>
<td>0.05</td>
<td>45</td>
<td>3 x 10^-3</td>
<td>7.5</td>
<td>1.5 x 10^3</td>
<td>1 x 10^4</td>
</tr>
</tbody>
</table>

These processes generate a sequence of erosional forms on rock surfaces in bedrock stream channels. Initial channels have relatively smooth floors. These are marked by longitudinal grooves, which mimic the longitudinal vorticity of the streaming fluid. Deeper erosion creates irregular surfaces that generate flow separation and/or kolks. As erosive activity concentrates at these sites, the result is greater accentuation of the surface irregularities [see Hancock et al., this volume]. A critical threshold has to be crossed to achieve this change from longitudinal forms to the production of irregular pockholes.

Experimental studies of fluvial erosion utilizing simulated bedrock [Shepherd and Schumm, 1974] indicate that a sequence of erosional bedforms may develop in bedrock as a function of time. First to appear in these experiments were the faint streaks of longitudinal lineations associated with potholes and transverse erosional ripples. The lineations then became enlarged into prominent longitudinal grooves. Eventually the grooves decreased in numbers, and finally one narrow, deep inner channel formed. In the layered basalt bedrock of the Channeled Scabland inner channels develop headwardly by the recession of subfluvial cataracts [Baker, 1978b]. Multiple horseshoe-shaped headcuts separate the inner channels from scabland surfaces marked by potholes and longitudinal grooves (Figure 1).

**THE KATHERINE GORGE EXAMPLE**

The Katherine Gorge is a 20-km long canyon developed in jointed, resistant sandstone. It is located in the north-central part of Australia (Figure 2), 32 km northeast of the town of Katherine, Northern Territory. The gorge is a slot-like chasm averaging 50 to 150 m wide and 40 to 60 m deep (Figure 3). Linear side canyons join the main gorge; these tributary mouths are ideal sites for slackwater sediment accumulation during rare, great flows (Figure 4).

The Katherine Gorge shows many morphological similarities to the Channeled Scabland. Inner channels are cut through broad surfaces of the very resistant quartzite bedrock (Figures 3 and 5). Locally, flood water even exceeds the capacity of the gorge, spilling across adjacent uplands (Figure 6). This latter phenomenon is a type of "overfitness" [Dury, 1964]. Overfitness is a characteristic of the Channeled Scabland in which flood flows exceed the capacity of stream valleys. Although such a condition would not persist long in an alluvial valley, the resistance of bedrock provides an opportunity to preserve overfit stream relationships.

**EXAMPLES FROM CENTRAL INDIA**

The Narmada and Tapi Rivers in central India (Figure 7) are situated in an environment typical of the monsoon tropics, with large floods during the summer monsoon season. Although the two rivers differ in basin size and morphology they have two hydro-geomorphic characteristics in common: high seasonal variability in the volume of flow and sediment load, and high-magnitude floods associated with monsoon depressions originating over Bay of Bengal [Kale et al., 1994].

The Narmada and Tapi are characterized by both alluvial and bedrock channels. The morphological characteristics of the bedrock and alluvial reaches are strikingly different and reflect the control of lithology, gradient and flood processes. The bedrock reaches are characterized by rapids, waterfalls, scablands, inner channels and boulder berms. The