5 Channeled Scabland morphology

VICTOR R. BAKER

Summary

The Channeled Scabland comprises a regional anastomosing complex of overfit stream channels that were eroded by Pleistocene megaflooding into the basalt bedrock and overlying sediments of the Columbia Plateau and Columbia Basin regions of eastern Washington State, USA. Immense fan complexes were emplaced where sediment-charged water entered structural basins. The cataclysmic flooding produced macroforms eroded into the rock (coulees and trenched spur buttes) and sediment (streamlined hills and islands). Several types of depositional bars also are scaled to the channel widths. The erosional mesoforms (scaled to flow depth) include longitudinal grooves, butte-and-basin scabland, potholes, inner channels and cataracts. These make up an erosional sequence that is scaled to levels of velocity, power per unit area and depths achieved by the cataclysmic flooding. Giant current 'ripples' (dunes) developed in the coarse gravel bedload, and large-scale scour marks were formed around various flow obstacles, including rock buttes and very large boulders.

5.1 Introduction

The Channeled Scabland region (Figure 5.1) is that portion of the basaltic Columbia Plateau and Columbia Basin that was subjected to periodic cataclysmic flooding during the late Pleistocene, resulting in a distinctive suite of flood-related landforms. Bretz (1923a, pp. 577–578) defined 'scablands' as 'lowlands diversified by a multiplicity of irregular and commonly anastomosing channels and rock basins eroded into basalt . . .' The term was in local use in reference to chaotically eroded tracts of bare basalt which occur in relatively large channels that the floods cut through the loess cover on the plateau. In a series of papers during the 1920s and 1930s, Bretz described the then amazing assemblage of landforms that included rock basins, anastomosing channel ways, cataracts, gravel bars and coulees. Field relations among many of these features, most notably the multiple levels of divide crossings, the cataracts, gravel bars and rock basins, led him to propose that an immense cataclysmic flood had swept across the Columbia Plateau in late Pleistocene time (Bretz, 1923b, 1928a; Bretz *et al.*, 1956). The source for this flood was eventually established to be glacial Lake Missoula, which had been impounded over a large region of western Montana because of a lobe of the Cordilleran Ice Sheet that extended into northern Idaho (Pardee, 1942).

The central figure in the controversy is J Harlen Bretz, the University of Chicago professor (1882–1981; Figures 1.1 and 5.2) and who formulated the hypothesis of cataclysmic flooding as the origin for the unusual landforms in this region (Baker, 1978a, 1981). Bretz (personal communication, 1977) recalled that he first conceived of the cataclysmic flood hypothesis when he saw a topographic map depicting the immense Potholes Cataract. His hypothesis remained highly controversial for decades (Baker, 1978a) but it gradually gained acceptance in the light of continued discoveries, including the giant current 'ripples' (dunes) on gravel bar surfaces (Pardee, 1942; Bretz *et al.*, 1956), credible mechanical explanations for the landforms (Baker, 1973) and additional examples of megaflood landscapes on Earth (Malde, 1968) and Mars (Baker, 1982). Thus, the current rapidly accelerating research on magaflooding derives much of its historical legacy from the pioneering studies of the Channeled Scabland by Bretz. Indeed, scabland landforms and their genesis are commonly cited in regard to current controversies over processes associated with phenomena as diverse as high-energy tsunami erosion of rocky coastlines (Bryant and Young, 1996), subglacial erosion (Shaw, 2002; Denton and Sugden, 2005; Lewis *et al.*, 2006) and landforms produced by large-scale flooding on Mars (Baker, 1982, 2001; Burr *et al.*, 2002).

Controversy also remains in regard to the number, timing, relative magnitudes and sources of the late Pleistocene floods that impacted the Channeled Scabland region (Baker and Bunker, 1985; Waitt, 1985; Smith, 1993). Recent work from the Columbia Gorge, downstream of the Channeled Scabland, documents at least 25 megafloods (flows with peak discharges of at least $1 \times 10^6\,m^3s^{-1}$) that occurred after about 20 000 years ago (Benito and O'Connor, 2003). However, only six or seven of these exceeded $6.5 \times 10^6\,m^3\,s^{-1}$, while at least one reached $10 \times 10^6\,m^3\,s^{-1}$). One of the smaller megafloods was from Lake Bonneville (O'Connor, 1993). Shaw *et al.* (1999) proposed that flooding emanated from beneath the Cordilleran Ice Sheet, a view that is disputed by Atwater *et al.* (2000).

This chapter will briefly review some of the now-classical morphological elements of the Channeled

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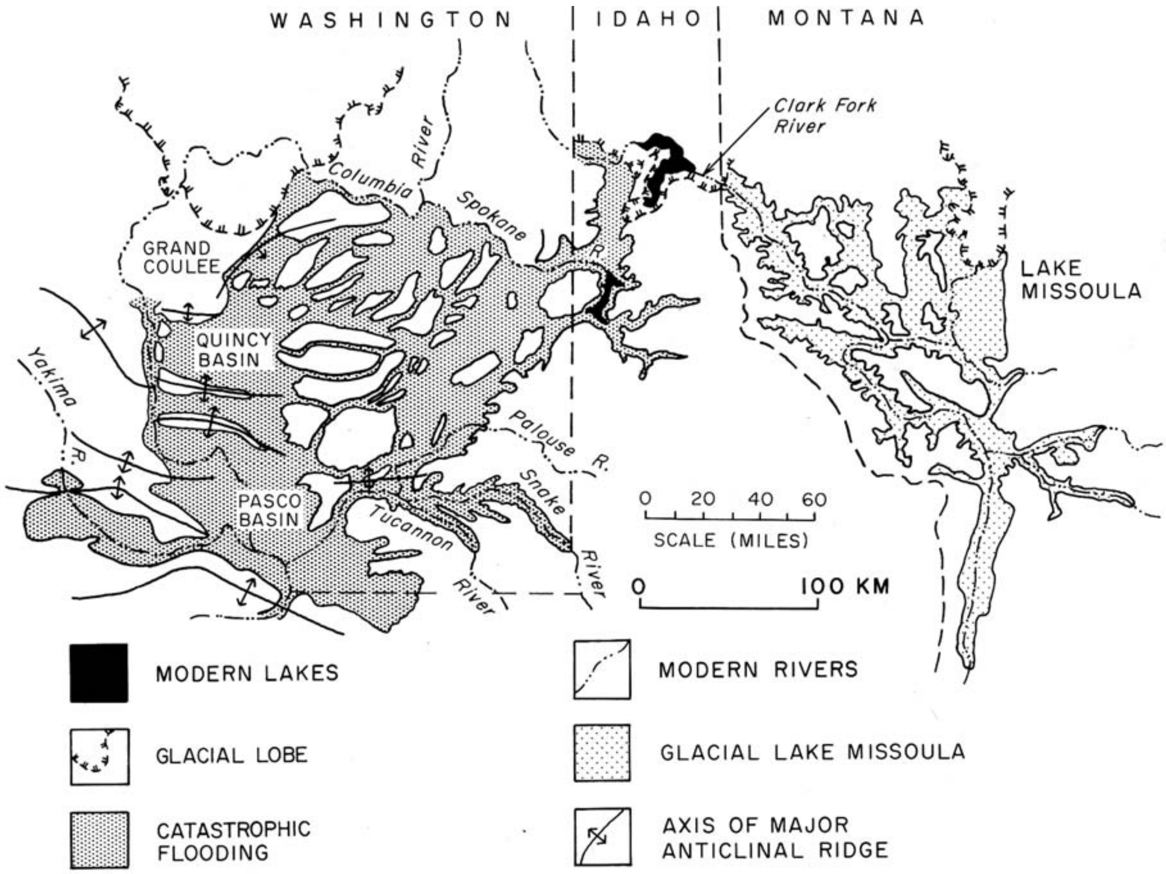

Figure 5.1. Location of the Channeled Scabland (left) in relation to glacial Lake Missoula.

Scabland, which divides into four major scabland tracts (Figure 5.3). From east to west these are (1) the Cheney–Palouse Tract, which heads to the southwest of Spokane and enters the Snake River Canyon with the Palouse River; (2) the Telford–Crab Creek Tract, which heads about 60 kilometres to the west of (1); (3) the Grand Coulee, which makes a single great gash through the divide about 60 kilometres west of (2); and (4) Moses Coulee, another 30 kilometres west of (3), which heads to the south of the divide in the marginal area of the Pleistocene Okanogan Lobe of the Cordilleran Ice Sheet.

5.2 Regional patterns

5.2.1 Anastomosis

The term 'anastomosis' was used by Bretz (1923a) to describe the pattern of scabland channels. Bretz (1923b) used both 'anastomosing' and 'braiding' to describe the pattern of scabland tracts, which he viewed as the individual elements in what he named 'channeled scablands' (Bretz, 1923b, p. 618). However, Bretz (1924, p. 148) seems to prefer the term 'anastomosing channels' to designate the chaotically eroded scabland channels that divide around steep-walled rock islands. Anastomosis occurs in the Channeled Scabland because preflood valleys did not have the capacity to convey the immense flood discharges that were imposed upon them. The floodwater filled the valleys to such an extent that water spilled across divides between the valleys. In this way the preflood valleys were transformed to a complex of dividing and rejoining channelways. This spilling across preflood divides produces a pattern of large-scale dividing and rejoining of channel ways that is cut into the basalt bedrock of the Columbia Plateau (Figure 5.3). Unlike the braided patterns that develop in alluvial rivers, scabland anastomosis does not involve deposition as a primary component of the overall pattern.

Although Bretz (1923a, 1924) clearly applied the term to bedrock channel morphologies in the Channeled Scabland, anastomosing river patterns were commonly confused with braided patterns in alluvial streams. For multichannel alluvial rivers a distinction between braiding and anastomosing is now common (Bridge, 2003), such that the former involves channels splitting around bars or islands, while the latter involves channels that diverge around

Figure 5.2. J Harlen Bretz photographed about the same time as his work in the Channeled Scabland.

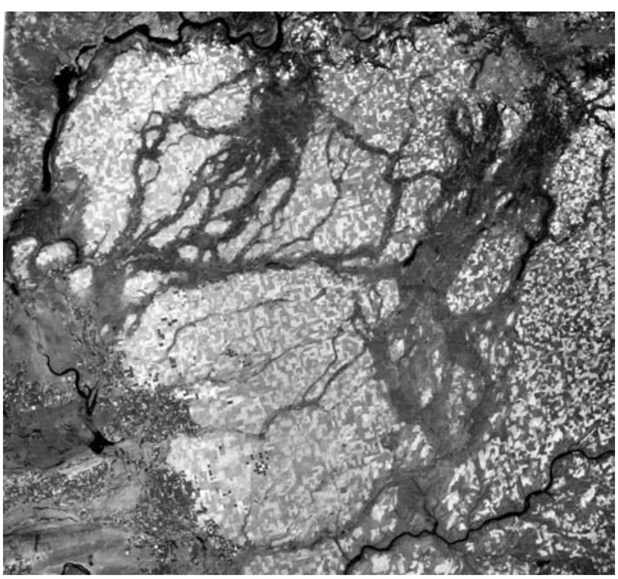

Figure 5.3. Anastomosing pattern of channels on the Columbia Plateau, showing three of the four main scabland tracts. From right to left, these are (1) the Cheney–Palouse tract, (2) the Telford–Crab Creek tract (top, centre), and (3) the Grand Coulee (upper left). This Landsat image (E-1381–18142) was acquired on 8 August 1973. It shows an area 180 × 200 kilometres. The Ephrata Fan (Figure 5.4) is located at the right-centre of the image.

floodplain areas. Moreover, the term 'anabranching', originally applied to multi-channel alluvial streams in Australia (Jackson, 1834, p. 79), is also applied to channels splitting around areas of floodplain (Nanson and Knighton, 1996). Bridge (2003) notes that these terms are not mutually exclusive, such that very large braided rivers, like the Brahmaputra, are both braided and anastomosing.

5.2.2 Overfitness

Misfit streams are either too small or too large for the valleys that they presently occupy (Dury, 1964). Although underfit streams are most often cited in the geomorphological literature, the overfit variety was recognised (Dury, 1964) as the result of sudden increases in discharge that produced such great channel enlargement that the channel became larger than the original valley that previously contained it. The Crab Creek valley near the town of Wilson Creek affords excellent examples of the overfitness generated by the cataclysmic flooding of the Channeled Scabland (Bretz, 1928b; Bretz *et al.*, 1956).

5.2.3 Coulees and hanging valleys

In the northwestern USA, the term 'coulee' is applied to very large steep-walled, trench-like troughs that often contain no stream along the valley floor. These are commonly the spillways and flood channels of the overall scabland plexus and many were parts of preflood fluvial valleys that formerly were more shallowly incised into the basalt plateau. Hanging valleys occur where the tributaries to these valleys are no longer graded to the main valley floor because of its deepening and widening by the cataclysmic flood scour. Examples occur in Moses Coulee and Lenore Canyon, where the preflood tributaries enter cliff faces on the coulee margins at elevations 50 to 100 or more metres above the coulee floor.

5.2.4 Fan complexes

Large fan complexes occur where constricted cataclysmic flood channel ways debouche into large structural basins. A well-developed example occurs where the floodwaters from the lower Grand Coulee expanded into the wide Quincy Basin in the west-central part of the Channeled Scabland (Figure 5.3). This is the Ephrata Fan (Figure 5.4). The deposit is alternatively interpreted as (1) an immense subfluvial expansion bar deposited at maximum flood stage that was modified by subsequent erosive flows (Baker, 1973), or (2) an outwash plain (sandur) formed by the coalescence of multiple bars emplaced by multiple jökulhlaup floods (Rice and Edgett, 1997). Another large fan complex occurs where the cataclysmic flows through the Columbia Gorge debouched into the Willamette lowland. This 'Portland Delta' (Bretz, 1925; Trimble, 1963) is characterised by an immense horseshoe-shaped scour hole developed around

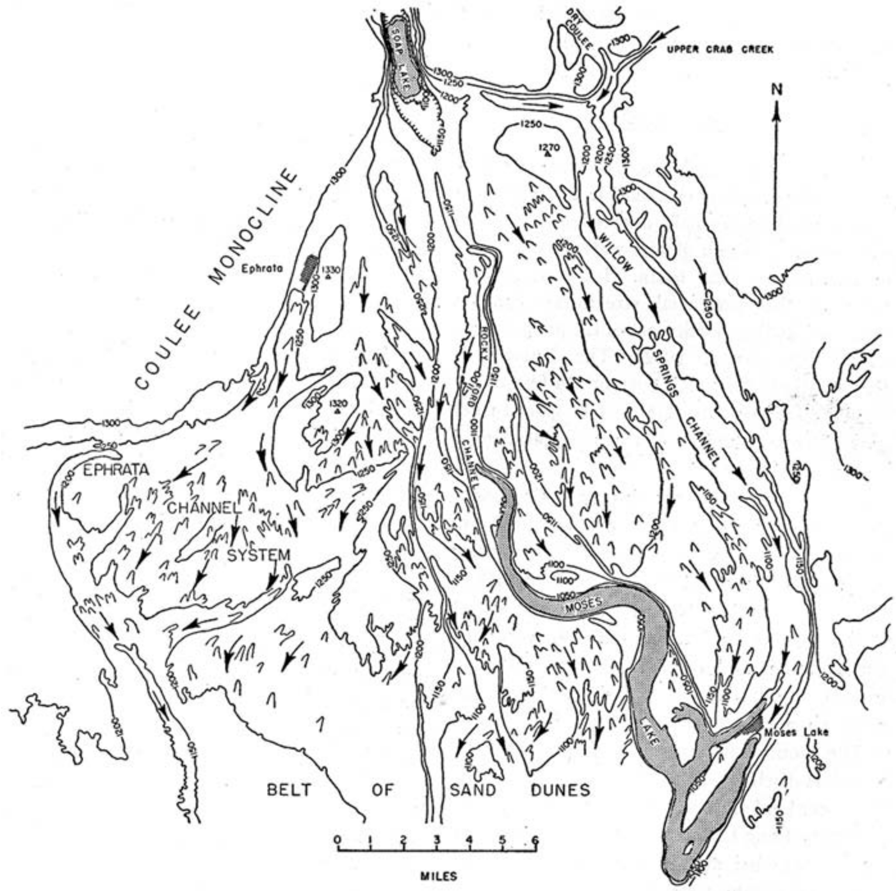

Figure 5.4. Topographic map of the Ephrata Fan complex at the northern end of the Quincy Basin. The arrows show the inferred surface flow directions. (The figure is from Bretz (1959), p. 33.)

the upstream end of large bedrock knob, Rocky Butte, in the northern part of Portland, Oregon.

5.3 Macroscale erosional surface forms

Southard (2003) applies the term 'surface form' to geometrical features that develop on a sedimentary surface by the action of a fluid over that surface. He prefers this term to that of 'bedform', which has come to have ambiguous meaning. Erosional surface forms on rock are termed 'sculpted forms' by Richardson and Carling (2005). The megaflood erosional and depositional surface and sculpted forms of the Channeled Scabland are classified in a hierarchical system, introduced by Baker (1978b), following a system that was applied to alluvial rivers by Jackson (1975). The scabland system (Table 5.1) has both depositional and erosional elements. The macroscale elements are scaled to channel widths. The mesoscale forms are scaled to channel depths.

The large erosional forms of scabland channels consist of eroded channel ways and the residual uplands between them. The channels fit into a regional anastomosing pattern, described above (Figure 5.4); they may locally contain inner channels, cataracts, butte-and-basin scabland and longitudinal grooves, which are their mesoscale erosional forms, to be described below.

5.3.1 Trenched-spur buttes

Prior to the megaflooding, the topography just west of Wilson Creek (Figure 5.5) was that of a gently meandering valley, incised through the loess-mantled uplands into the underlying basalt. Here the valley meandered with a wavelength of about 600 metres. The megaflooding completely filled this pre-flood valley such that water spilled over divides into adjacent valleys. Bretz (1928b) proposed that the flooding could not tolerate the leisurely meandering curves of the deeply incised pre-flood valley. Slip-off slopes of the meander bends were attacked vigorously to produce what he called 'trenched-spur buttes' (Figure 5.5). Huge streamlined bars were deposited downstream of the former valley bends and many of these have giant current 'ripples' on their surfaces (Figure 5.5).

Table 5.1. Erosional and depositional landforms of the Channeled Scabland

Scale	Eroded in rock	Eroded in sediment	Deposition
Regional patterns	Anastomosis		Fan complexes
Macroforms (scaled to flow width)	Coulees trenched spur buttes	Streamlined hills and islands	Longitudinal bars Eddy bars
Mesoforms (scaled to flow depth)	Longitudinal grooves Butte-and-basin scabland Inner channels cataracts Potholes	Scour holes	Giant current ripples (dunes)

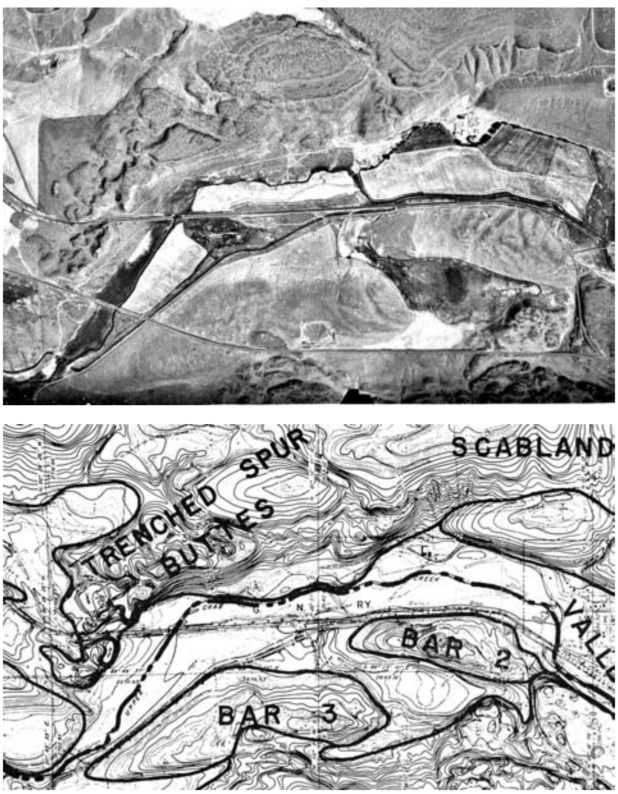

Figure 5.5. Trenched-spur buttes (left centre) and depositional bars immediately west of Wilson Creek, Washington. The photograph (top) was taken 30 June 1961, and it shows an area 2 × 3.5 km. The contour map (bottom) (U.S. Bureau of Reclamation Map G5883) shows the same area (from Bretz (1959), Plate 4). The contour interval is 0.6 metres (2 feet).

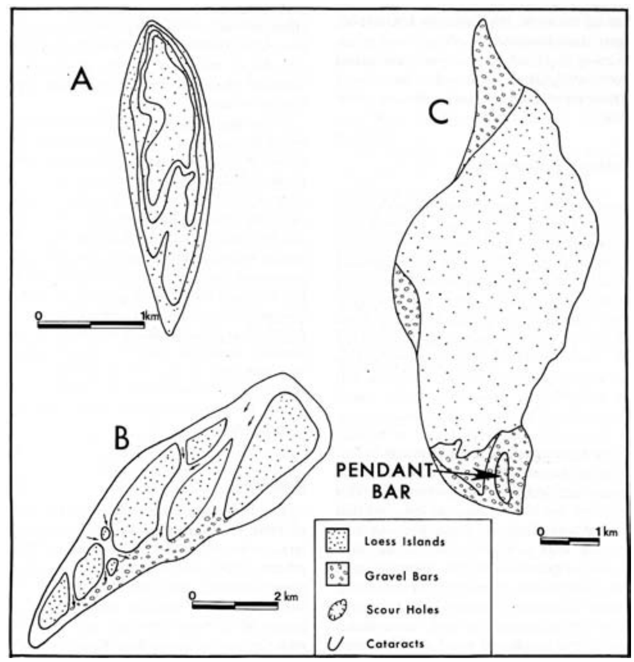

Figure 5.6. Morphologies of various loess islands and flood-modified loess hills in the Cheney–Palouse scabland tract. (A) Loess hill showing highly streamlined morphology that resulted from full submergence during the flooding. (B) Partially submerged loess island showing major divide crossings (arrows) and gravel deposition to form a leeward accumulating bar. (C) Fully emergent loess island with margins shaped by floodwater flow and gravel bar accumulations upstream, downstream and marginal to the island. (The figure is from Patton and Baker (1978), p. 123.)

5.3.2 Streamlined hills and islands

The eastern portions of the Channeled Scabland, particularly the Cheney–Palouse tract (Patton and Baker, 1978), contain spectacular examples of kilometre-scale hills that show distinctive flow streamlining of the edges (‘islands’) and, in some cases, tops (Figure 5.6). These generally occur in local clusters, organised in a braid-like pattern within the overall scabland complex. The hills are composed predominantly of loess that was not stripped from the underlying basalt. They may also partially contain gravel and cementing petrocalcic horizons that derive from more ancient phases of cataclysmic flooding than those responsible for the streamlining.

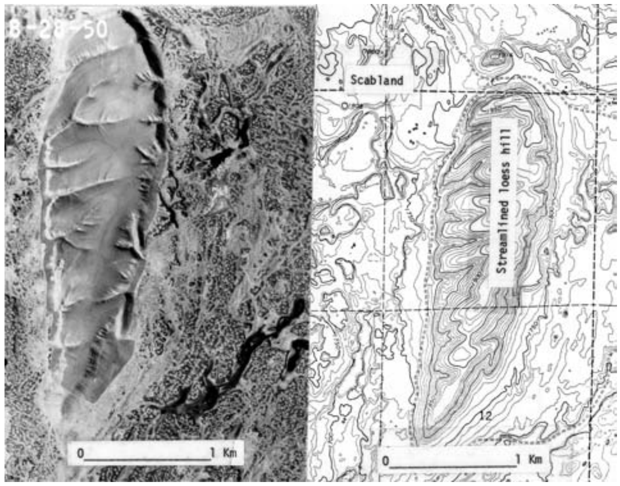

Figure 5.7. Detailed morphology of a streamlined loess 'island' in the Cheney–Palouse scabland tract. Groove and butte-and-basin scabland can be seen on the channel floor marginal to the loess hill. Water velocities were on the order of 12 m/s and flow depths were about 30–40 m during the flooding (Baker, 1973). The contour interval for the map is about 3 m (10 feet). (The figure is from Baker (1978b), p. 90.)

The streamlined hills generally rise up to 50 m above the surrounding scabland areas, and they are commonly 1–4 km long and 0.5 km wide. Bretz (1923b) first recognised their remarkable shape, with steep, ungullied bounding hillslopes that converge upstream to prow-like terminations and downstream to tapering tails (Figure 5.7). Baker (1974) compared the planimetric chapes to the lemniscate form, used by Chorley (1959) to characterise the streamlining of glacial drumlins. In a more detailed analysis of the lemniscate shape, Komar (1984) found that it provides a close representation of symmetrical airfoils (Joukowski sections), and thus serves to characterise the streamlining process.

Streamlining serves to reduce the drag or resistance to a flowing fluid, resulting in distinctive relationships among lengths, widths and areas for the landforms. These have been demonstrated for both streamlined hills in the Channeled Scabland and for analogous forms on Mars (Baker and Kochel, 1978; Baker, 1979). Direct measurements on airfoils in both air and water demonstrate that the minimisation of drag occurs for length-to-width (L/W) ratios in the range of 3 to 4 (Komar, 1983). Baker and Kochel (1978) and Baker (1979) showed that scabland L/W values average 3.25, confirming their minimisation of drag.

5.4 Macroscale depositional surface forms

The term 'bar' is used for a great variety of large-scale depositional landforms in streams and rivers. Here the term is applied to all the depositional macroforms in scabland channels. Because there is no universally accepted classification for fluvial bars, a scheme has evolved for local use in the Channeled Scabland and adjacent areas. The scheme is based on the relationship of the bars to large-scale flow patterns in a local scabland channel reach, as recognised by Bretz (1928b), Bretz *et al.* (1956) and Baker (1973). As with alluvial rivers, scabland bars are macroforms, in the sense of Jackson (1975) and Church and Jones (1982), such that their dimensions scale to channel widths.

Many coarse gravel-transporting alluvial rivers assume a braided pattern in which linguoid and transverse bars form with relatively low profiles. Such rivers have relatively high width-to-depth ratios for their channel cross-sections. Scabland channel ways, in contrast, are relatively narrow and deep, as characteristic of resistant-boundary streams, such as those that are incised into bedrock (Baker, 1984). As consequence of this, scabland bars are commonly tens of metres in height, with an internal structure of foreset bedding (Baker, 1973).

5.4.1 Longitudinal bars

These bars are elongated parallel to the predominant flow direction. They commonly alternate at the bends of the palaeomeanders in scabland valleys that were transformed to flood channel ways (Figure 5.5). Unlike the broad, low-lying bars of wide, shallow braided rivers, the scabland longitudinal bars are high, mounded and streamlined hills of gravel, unusually tens of metres thick. Internal stratification is dominated by foreset bedding that developed on avalanche faces by accretion to the downstream margins of the bar. Many bars developed from multiple episodes of such accretion, either during the course of a single prolonged megaflood, or as the result of multiple floods.

Many longitudinal bars develop immediately downstream of bedrock projections on the scabland channel floors (Figure 5.8). Malde (1968) introduced the term 'pendant bar' for this landform, based on studies of the Pleistocene Bonneville megaflood in Idaho, and Baker (1973) found that similar features were common in the Channeled Scabland.

5.4.2 Eddy bars

These bars occur at the mouths of alcoves or valleys that were tributary to the valleys that were invaded by the megaflooding. Along the eastern margins of the Cheney–Palouse scabland tract nearly every tributary valley is blocked at its mouth by this kind of bar (Bretz, 1929). Subsequent erosion by the tributary stream may breach the blockade but smaller tributaries and alcoves may retain the original morphology of the eddy bar. Excellent examples of these occur in the basin of glacial Lake Missoula

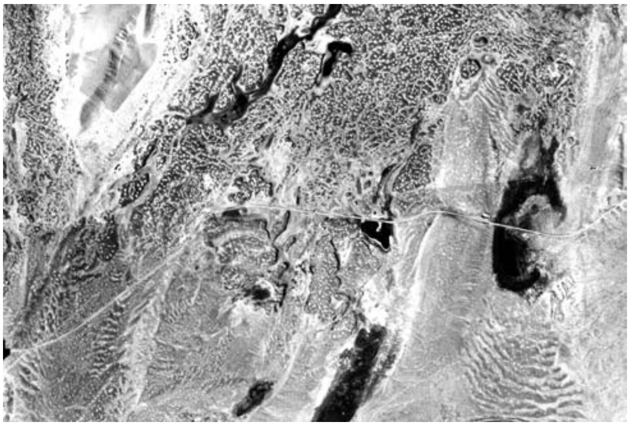

Figure 5.8. Pendant bar (right half of image) and scabland topography from near Macall, Washington. Note the giant current 'ripples' (GCRs) at the bottom left and bottom right. The cataclysmic flows were from top to bottom in this scene. The photograph shows an area 3 × 4.5 kilometres. It was taken 28 August 1950.

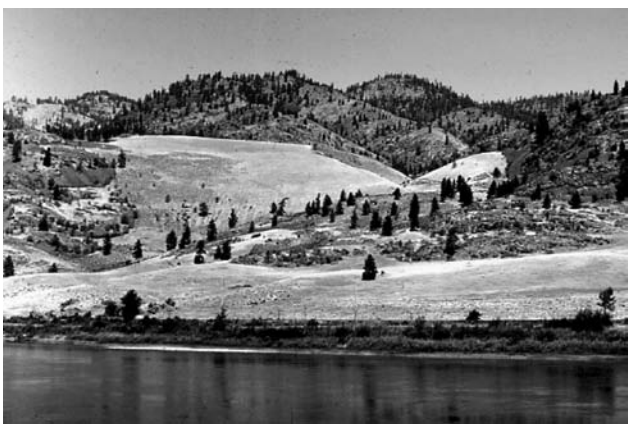

Figure 5.9. Eddy bar in the former basin of glacial Lake Missoula.

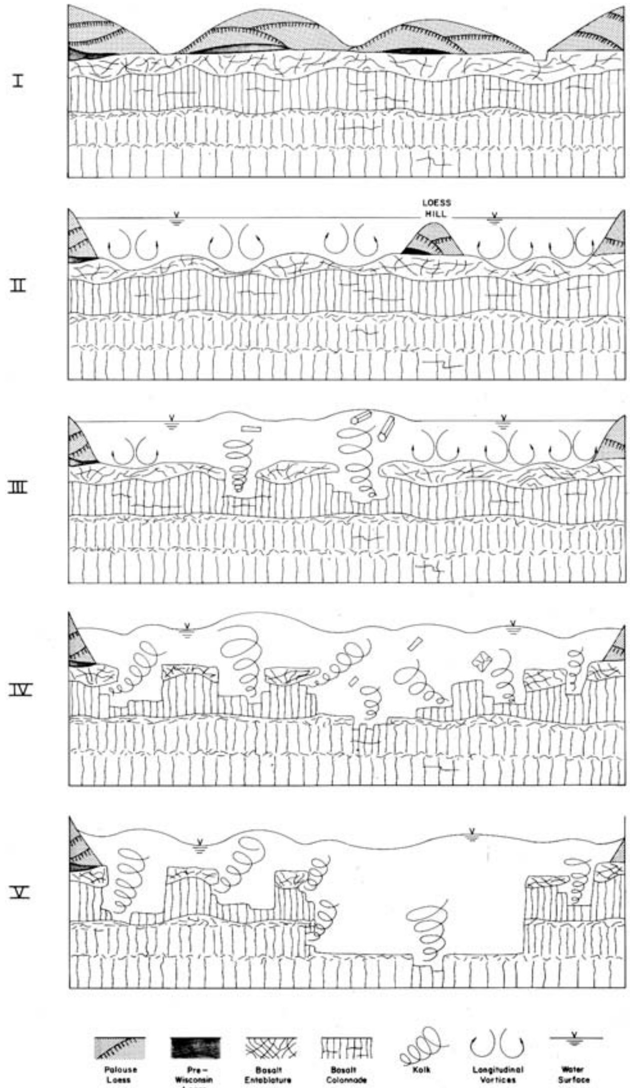

Figure 5.10. Schematic cross-sections showing the inferred sequence of flood erosion of a scabland complex. The numbered stages of erosion are described in the text. They are related to flow hydraulics in Table 5.2. (The figure is from Baker (1978b), p. 105.)

(Figure 5.9), where Pardee (1942) invoked them as evidence for the cataclysmic drainage of that lake.

5.5 Mesoscale erosional surface forms

5.5.1 Sequence of erosional forms

A sequence of erosional forms, recognised in flume experiments by Shepherd and Schumm (1974), seems to characterise scabland channel ways (Baker, 1974, 1978b; Baker and Komar, 1987). This sequence can be illustrated with a series of schematic cross-sections (Figure 5.10). The first floodwater to enter the eastern Columbia Plateau regions would encounter the Palouse Hills topography of loess overlying the jointed basalt bedrock (Phase I of Figure 5.10). The high-velocity floodwater would easily remove much of the loess, leaving local remnants as streamlined loess hill or 'islands' (Phase II). Encountering the surface of the uppermost basalt flow, the water would begin by eroding longitudinal grooves (Figure 5.11), probably associated with longitudinal vortex structure in the macroturbulent flow field (Baker, 1979). Continued incision into the resistant basalt flow would eventually encounter columnar jointing, sometimes at the top of a flaring colonnade along a rolling surface created by the inflationary nature of the primary basalt flow emplacement. Hydraulic plucking of the basalt columns (Phase III) would then lead to the development of large-scale, basin-like potholes with intervening buttes. With enlargement and coalescence of potholes, the surface would develop to the butte-and-basin scabland (Phase IV) that typifies many scabland channel ways (Figure 5.12). Continued development eventually

Figure 5.11. Oblique aerial photograph of the Dry Falls cataract complex showing longitudinal grooves upstream of the cataract. Flow was from top to bottom in this scene. Note the prominent rock basins at the lower right. These basins are relatively narrow and deep.

Figure 5.12. Butte-and-basin scabland in Lenore Canyon, lower Grand Coulee. Note the dirt roadways for scale.

results in the formation of a dominant inner channel (Phase V), which usually heads at a rock step, or cataract (Figure 5.11).

An excellent example of this whole sequence can be seen at the Dry Falls cataract complex (Figure 5.13). The Dry Falls complex is 5.5 km wide and 120 m high. It consists of two western, horseshoe-shaped head cuts with plunge pools at their base and an eastward-extending inner channel. Dry Falls heads an inner channel that was eroded into the fractured basalt of the Coulee Monocline (Bretz, 1932). Prominent longitudinal grooves are developed on the basalt surface located immediately upstream of the cataract head (Figure 5.11).

Richardson and Carling (2005) restrict the term ‘pothole’ to round, deep depressions that are not eroded by plucking. Scabland rock basins, in contrast, are commonly relatively shallow and wide, though much larger in scale than the potholes usually found in bedrock river channels.

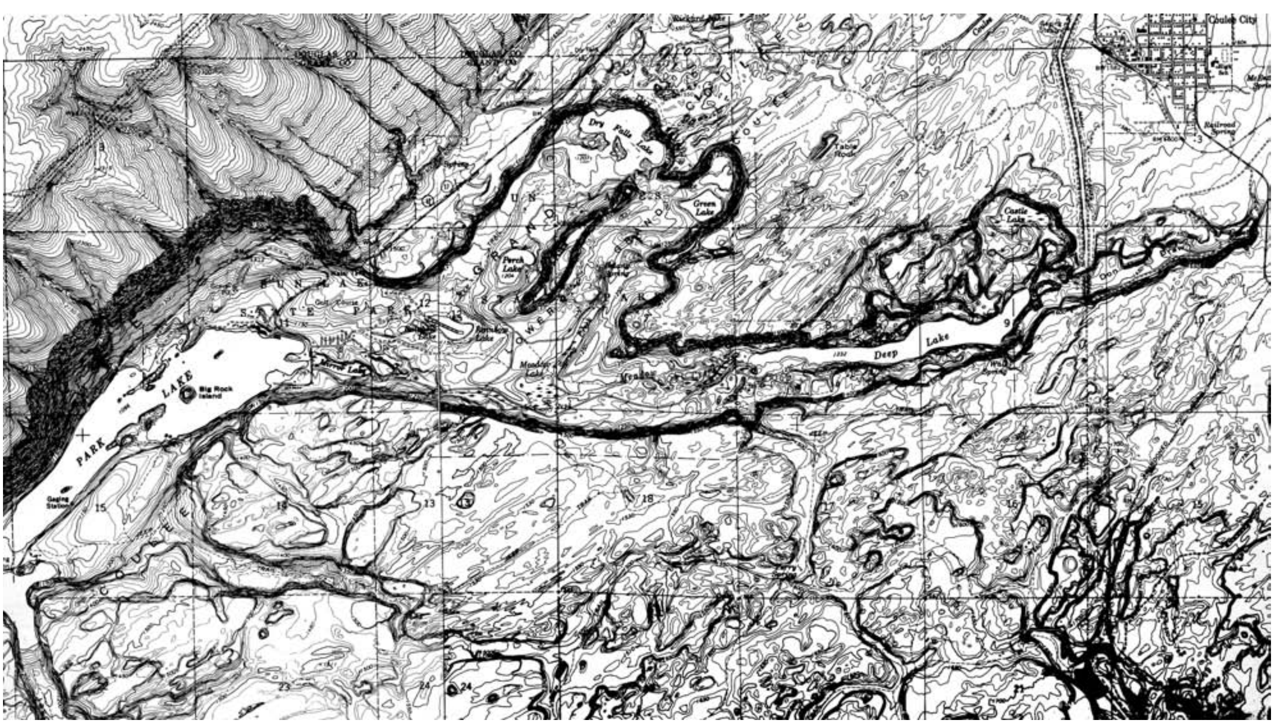

Figure 5.13. Topographic map of the Dry Falls cataract complex (compare to Figure 5.11).

5.5.2 Scour marks

Various obstacles to flow in scabland channels, such as large boulders or bedrock knobs, resulted in deformed flow streamlines for the deep cataclysmic floods. The hydrodynamics of the resulting flow involves large-scale vortex formation at the obstacle front and in its wake. The process is well known in the engineering literature concerned with scour during flooding at bridge piers (Shen, 1971). Baker (1973) described this process in relation to an 18 m long boulder on the Ephrata Fan surface. Herget (2005) describes many similar examples from the Altai cataclysmic flood region of central Asia.

Whether the cataclysmic flows scoured or deposited upstream from obstacles depends on the flow Reynolds number, which is directly proportional to the approach velocity of the flow and the obstacle diameter. At high Reynolds number, erosion occurs for both the 'horsehoe vortex' that forms at the upstream side of an obstacle and the wake vortex system that forms at its downstream end, resulting in the distinctive scour marks. However, at low Reynolds number, deposition may occur. This latter process can result in the pendant bars, described above, and, less commonly, in gravel bars that develop on the upstream margins of scabland flow obstacles and streamlined loess hills (Figure 5.6C).

Figure 5.14. Giant current 'ripples' (dunes) near Marlin, Washington. The largest dune forms have heights of about 2–3 metres and a spacing of up to 60 metres (Baker, 1973). The aerial photograph is dated 17 August 1957. It shows a region of about 2.7 by 3 km.

5.6 Mesoscale depositional surface forms

5.6.1 Giant current ripples (dunes)

Bretz *et al.* (1956) applied the name 'giant current ripples' to the mesoscale transverse gravel depositional forms of the Channeled Scabland. Following Pardee's (1942) discovery of similar features in the basin of glacial Lake Missoula, Bretz *et al.* (1956) identified about a dozen examples. The Wilson Creek area was studied in some detail, and several examples were found of 'ripple' trains superimposed on gravel bars (Figure 5.14). Subsequently, Baker (1973) documented 60 of the most prominent sets of 'giant current ripple' (GCR) forms. Unpublished work indicates that there are certainly well over 100 GCR occurrences throughout the regions impacted by Missoula megaflooding.

Current terminological convention (Ashley, 1990) classifies various flow-transverse, mesoscale depositional surface forms as 'dunes'. For gravel compositions, in contrast to sand or silt, dunes form at flow strengths (velocity, shear stress or stream power) just above the threshold for bed movement (Southard, 2003). In the relatively shallow flows that are typical for alluvial rivers, dunes are replaced by antidunes when the flow strengths increase above a few metres per second (Southard, 2003). Like the various bedforms classed as 'large-scale asymmetrical ripples', 'megadunes' and 'sand waves', dunes form in the upper part of the lower flow regime, at Froude numbers less than 1.

The striking appearance of the scabland GCR forms on aerial photographs (Figure 5.14) arises from local post-depositional factors. Deposition of aeolian silt in the swales between the surface-form crests locally results in differences in vegetation cover. In drier regions, the gravelly GCR summits are covered by sagebrush (*Artemisia tridentata*) and the adjacent swales are covered by cheat grass (*Bromus tectorum*). In contrast, a prominent GCR occurrence in the wetter region near Spirit Lake, Idaho, has a second-growth forest cover in which the larger pine trees (*Pinus ponderosa*) occupy the relatively wet swales, but not the drier surface-form summits (Figure 5.15).

It is an interesting historical sidelight that when the Channeled Scabland GCRs were first seen on aerial photographs, H. T. U. Smith, who was accompanying Bretz for the 1952 summer field season, immediately recognised their form as that of dunes. Smith, of course, was presuming from their size and patterns that these were sand dunes. One can imagine the surprise when the field site visits were made, and it was found that the features were composed entirely of gravel, including many boulders (G. E. Neff, 1969, personal communication).

Table 5.2. Relationship of flow hydraulics to stages of scabland channel cross-sectional morphology (Figure 5.10)

Erosional stage	Description	Mean velocity ($m\,s^{-1}$)	Power per unit area (watts m^{-2})	Depth (m)
I–II	Streamlined loess hills	3–5	500–2000	30–100
II–III	Stripped basalt, grooves	3–9	500–3000	35–125
III–IV	Butte-and-basin scabland	7–15	2000–20 000+	100–250
IV–V	Inner channels	15–25	5000–25 000+	100–250+

Hydraulic data are from calculations by Baker (1973, 1978c) and Benito (1997).

Figure 5.15. Giant current 'ripples' (dunes) near Spirit Lake, northern Idaho. The largest dune forms have heights of up to 7 metres and a spacing of up to 125 meters (Baker, 1973). Flow was from right to left. The aerial photograph is dated 5 August 1958. It shows a scene 4.6 by 4.6 km.

An inventory of these surface forms by Baker (1973) shows that their chords (spacings) generally range from 20 to 200 m and their heights range from 1 to 15 m. The relationship of bedform height H (metres) to chord or spacing λ (metres) is very regular, and similar to that found for relatively straight-crested gravel dunes, approximately as follows (Baker, 1973; Carling, 1999):

$$H = 7 \times 10^{-3}\lambda^{1.5}.$$

In plan view these surface forms have crest lines that look similar to those of sand ripples in rivers. However, the scabland forms are composed of gravel, cobbles and boulders. They have an internal structure of foreset bedding with openwork gravel textures.

5.7 Palaeohydraulic implications

Some evidence for the hydraulic implications of various scabland landforms comes from hydraulic modelling studies. Benito (1997), working in the Columbia River Gorge, found that the morphological sequence described in Figure 5.10 can be related to various measures of flow strength, specifically mean flow velocity, stream power per unit area of bed, and depth (Table 5.2). Note that the levels of flow strength are much larger than what is achieved in most contemporary terrestrial rivers (Baker and Kochel, 1988) but comparable to the values for other ancient megafloods (Baker, 2002).

The palaeohydraulic implications of the GCRs are problematic. Baker (1973) developed correlations for bedform dimensions (chord and height) to maximum flood flow strength variables (mean flow velocity, stream power per unit area of bed, and depth–slope product). Baker's (1973) peak flow velocities at the GCR locations range from 8 to 18 metres per second for flow depths of 20 to 150 metres. Power values for these peak flows fall in the range of 2000 to 20 000 watts per square metre (Baker, 1973). These values are comparable to those determined by Benito (1997) (see Table 5.2) for the butte-and-basin scabland with which the GCRs are commonly associated (e.g. Figures 5.7, 5.8). Of course, it is likely that the GCRs formed after the flood peak, such that they were emplaced at lower values of flow strength. Prominent armouring of GCR surfaces with a lag of coarse particles suggests that they were modified during waning flow stages (Baker, 1973).

In contrast to the results of Baker (1973), studies of the very similar-appearing giant current ripples (GCRs) of the Altai region in Siberia indicate mean flow velocities of 1.5 to 8 metres per second (Carling, 1996), and 5 to 11 metres per second (Herget, 2005), for flow depths of about 20 to 80 metres. This discrepancy probably occurs because the Channeled Scabland GCR morphologies were correlated to peak flow conditions (Baker, 1973), and not to the flows lower than the maxima, which most likely generated the GCRs. The strong correlations found by Baker (1973) probably reflect the properties of the reaches in which the surface forms developed. Both the peak flow hydraulics and the waning flow hydraulics at the time of GCR formation would have correlated to these reach properties.

5.8 Discussion

Bretz once considered the landforms of the Channeled Scabland to be unique in the world. In being so, he reasoned, their cataclysmic origin might be more acceptable to his contemporary geologists who held to an overly rigid form of uniformitarianism. In this conclusion he was wrong. Cataclysmic flood landscapes have now been documented in many parts of the world (Baker, 2002). Spectacular examples of giant current bedforms occur in central Asia (Baker *et al.*, 1993; Carling, 1996; Rudoy, 2005), along with immense gravel bars and scour marks (Herget, 2005). Streamlined hill and bar morphologies occur in the glacial lake spillway channels of central North America (Kehew and Lord, 1986). Moreover, the patterns, forms and processes evident in the Channeled Scabland have helped inform understanding of processes that occur at a smaller scale in modern bedrock channels that are highly influenced by extreme flood processes (Baker, 1977, 1984; Baker and Kale, 1998). This is one controversy in which Bretz would probably have been pleased to concede defeat. What better outcome from his point of view than to have a kind of reverse unformitarianism derive from his famous controversy with the overly strict adherents to the more common form of that logically flawed doctrine (see Baker, 1998)?

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