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CATASTROPHIC FLOODING
The Origin of the Channeled Scabland

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In 1969 Bretz published a reflection on his fifty years of research on the catastrophic flooding of the Channeled Scabland and nearby regions. In that paper (Bretz, 1969) he presented a detailed list of the many problems that were left unanswered by his own work. The list can be divided into two categories: (1) stratigraphic problems, and (2) process problems. These comments will report on progress in answering Bretz's questions. The stratigraphic problems have been addressed by many researchers employing a variety of new stratigraphic tools unavailable to Bretz. The work on the process implications of the Bretz hypothesis began with the editor's studies (Baker 1971, 1973a, 1973b).

PALEOHYDRAULIC STUDIES

In 1973 Baker described evidence of the high-water mark left by the largest of the Lake Missoula outbursts. Using engineering hydraulic calculation procedures, he estimated the flood discharges and flow velocities for the flooding. This approach is updated in the report reproduced here as Paper 12. The key to the reconstruction of hydraulics is a "magic surface," the high-water surface of the flooding. That surface records the dynamic energy

variations of the flooding. The philosophy of its analysis is similar to that employed by Gilbert (1890) in his analysis of Lake Bonneville. For Gilbert it was the lake level that served as the key element in paleohydrologic reconstruction.

To the early investigators of the Columbia Plateau, the scabland complexes were a chaos of eroded terrains. The report reproduced here as Paper 13 shows there is order in the development of the scabland features. An important discovery is that the phenomenal flow velocities of the Missoula floods are dynamically consistent with the scale and the variety of erosional landforms in the Channeled Scabland. After fifty years Bretz's hypothesis of catastrophic flood erosion is no longer considered "outrageous."

Paper 14 emphasizes this point in the Cheney-Palouse scabland tract, the region selected by Flint (1938) as an ideal place in which to disprove the flood hypothesis. Note that the references for Papers 12 and 13 are found at the end of Paper 14. This reference list also provides many other sources on the geology and regional setting of the Channeled Scabland.

THE SCABLANDS OF MARS

The final reprint in this volume (Paper 15) presents the case for the Channeled Scabland as an analog to one class of channels on Mars. Orbital photographs of Mars obtained during the Viking space mission reveal the planet to possess a remarkable variety of channeled terrains (Baker 1979). Some channels form relatively small networks up to 100 km in length that resemble dendritic valley systems of the earth. The most spectacular channels, however, comprise great anastomosing complexes up to 100 km wide that can be traced 2000 km or more across the planet's surface. These zones are called "outflow channels" because they appear full-born at localized source regions, usually collapse zones. Paper 15 suggests that immense floods of water were released from within the planet, emanating from troughs that receded headward to form the channels. The collapse zones at the heads of the channels mark the last points of fluid release.

Much of Mars is heavily cratered, similar in some respects to the Moon. Closer scrutiny reveals that the martian craters are very different from those on the Moon (Carr et al. 1977). Instead of being surrounded by rays of ballistically ejected debris, the martian craters appear to have been formed by meteors that impacted a soupy mud. They are bounded by lobes of debris that *flowed* from

the impact sites. Abundant photographic evidence suggests that Mars was once underlain by a thick layer of permafrost, which probably contained a high percentage of ice (Carr and Schaber 1977). The great outflow channels probably developed from a variety of processes related to this permafrost. Local zones of volcanic heating may have built up pressure beneath the permafrost cap until the liquid water burst forth as great floods (Masursky et al. 1977). Another idea is that liquid water was trapped beneath the frozen surface layers until crustal warping caused pressure differences to develop (Carr 1978). When the pressure in a local zone reached a critical point, the water burst forth, draining the subsurface reservoir in much the same way that relatively small springs sometimes develop on the earth.

Whatever the mechanism of water release on to the martian surface, the outbursts produced an assemblage of erosional landforms that includes streamlined hills, anastomosing patterns, inner channels with recessional headcuts, bar-like forms, and grooves aligned parallel to the indicated fluid flow direction (Baker and Milton 1974; Baker and Kochel 1978, 1979). The scour features all occur below a definite "trim line," indicating that the responsible fluid had an upper flow boundary. The only terrestrial landscape that contains analogs to all the martian outflow channel landforms is the Channeled Scabland of eastern Washington.

The ages of the martian outflow channels are very difficult to estimate from photographic evidence alone. One method, looking at the number of impact craters that occur on the channeled surface, reasons that more craters per unit area will occur on older surfaces. Although this method provides relative ages, the absolute age in years requires an assumption concerning the rate of cratering. Current thinking relies on assumptions that suggest very old ages for the outflow channels, perhaps 1 to 3 billion years (Masursky et al. 1977; Neukum et al. 1979). If these ages prove correct, then the channels may have formed during an ancient episode of martian history, perhaps when the climate was warmer and the atmosphere denser than at present.

RECENT STRATIGRAPHIC RESEARCH

Bretz (1969) proposed, primarily on physiographic evidence, as many as eight separate scabland floods, of which at least four encountered an ice-blocked Columbia River and spilled over the

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northern margin of the Columbia Plateau. Bretz's four other floods were not diverted by ice and flowed down the Columbia River valley. Bretz (1969, p. 513) believed that the earliest plateau-crossing flood occurred during the Bull Lake glaciation, now considered correlative to the Illinoisan glaciation of the midwest United States (Pierce et al. 1976).

Baker (1973) noted that some of the physiographic relationships described by Bretz (1969) could be produced during the dynamic progression of a single flood. Only flood deposits recognized in a firm stratigraphic sequence can be considered unequivocal evidence for multiple flooding. The best stratigraphic information to date suggests that there certainly were multiple floods in the general vicinity of the Channeled Scabland. One, possibly two, floods were pre-Bull Lake and are overlain either by thick caliche or by Palouse Formation. The Palouse Formation is a sequence of loess units that mantles divide areas in the Channeled Scabland and was scoured by the Wisconsinan floods of Lake Missoula (Richmond et al. 1965). Patton and Baker (1978) describe the regional evidence for pre-Wisconsin (pre-Palouse) flooding.

Malde (1968) studied the catastrophic flood produced by the overflow and rapid lowering of Pleistocene Lake Bonneville. He traced the course of this flood through the Snake River Plain of southern Idaho to Hells Canyon. Malde interpreted the date of this event to be about 30,000 years B.P., based on a radiocarbon date for molluscan fossils associated with flood debris and on the relict soil profile developed on the flood gravel (Melon Gravel). The soil has a thick calcic horizon extending to depths greater than 2 m. The soil on the Bonneville Flood deposits is believed to have formed during and since the mid-Wisconsin (Bull Lake-Pinedale) interglaciation, or within the last 30,000 years.

Downstream from Hells Canyon at Lewiston, Idaho, probable Bonneville flood deposits are overlain by slackwater surge deposits from the last major episode of scabland flooding. Because Bonneville flooding was confined to the Snake River Canyon, it skirted to the south of the Channeled Scabland. Nevertheless, studies in the Pasco Basin may eventually recognize Bonneville Flood deposits in association with Missoula flood deposits.

The last major episode of scabland flooding, involving at least several individual floods, occurred between 18,000 and 12,000 years B.P. In the eastern Channeled Scabland the last major flood scoured channelways through the entire sequence of brown loess units that comprise the Palouse Formation. Small channels eroded

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into the flood deposits by postflood streams contain pale loess and loess-derived alluvium. The oldest soil profiles on postflood loess deposits show textural B horizons, with the $<2\,\mu$ size fraction increasing from 8 percent to 11 percent (Baker 1973a).

The dating of the last major scabland flooding episode is complicated by the fact that the catastrophic flood deposits occur in two facies. The main-channel facies can always be recognized as unequivocal flood deposition by its coarseness, sedimentary structures, angular boulders, broken rounds, erratics, and so forth. However, the slackwater facies consists of rhythmically bedded sands and silts deposited in the preflood tributaries to the scabland channels (Bretz 1929, 1930). An unequivocal flood origin can be established by continuous tracing between main-channel areas and slackwater areas, as in the Tucannon Valley sequence (Baker 1973a). At the Tucannon Valley one can follow a complete transition from chaotically deposited boulder and cobble gravel in the main channel (proximal facies) to rhythmites of sand and silt in slackwater areas (distal facies) 15 km up a preflood tributary of the main channel (Baker 1973a, pp. 42–47).

The slackwater facies of the Missoula flood deposits is the current subject of intense study concerning the number and timing of late-glacial floods in the Columbia River system. The upper portions of some slackwater sequences contain tephra layers that correlate to the "set S" pumice deposits of Mount St. Helens (Moody 1978; Mullineaux et al. 1978). The correlation points to a limiting upper date of about 13,000 years B.P. for the last major episode of catastrophic flooding to have affected the Columbia Basin in eastern Washington (Mullineaux et al. 1978). The regional distribution of this tephra makes it an important time-stratigraphic marker in the slackwater sequence.

Richard B. Waitt, Jr. (1979) has studied the remarkably thick late-glacial rhythmite sequences of the Walla Walla basin and the lower Yakima Valley, where he has found evidence for subaerial exposure following floodwater emplacement of some of the rhythmites. At the remarkable Burlingame Canyon section, Waitt counts at least thirty-eight well-formed distal facies rhythmites. One possible hypothesis for this new data is that each rhythmite represents a separate catastrophic flood event (Waitt 1979). Unfortunately, the proximal facies sediments for each of these inferred floods have not yeat been discovered. Thus, the possibility remains that single great floods can produce multiple *distal* rhythmites, so that the Burlingame section may represent a somewhat

smaller number of late Wisconsin flood events than given by the rhythmite count (Bjornstad 1980; Patton et al. 1979).

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