both from aerial photography and on the ground. Perhaps some way can be found to distinguish between boulders that are sapping or debris flow remnants and those that are from more recent falls of talus.

Acknowledgments

This is a remote sensing study of a nearly inaccessible canyon that the author has seen only from the air. The study could not have been done without the photographs taken by Carman W. Dunn on a Civil Air Patrol practice mission. Scanning of the slides was provided by MicroImages, Inc., Lincoln, Nebraska. Several of the features in the MIPS software were written by MicroImages in response to the needs of this study. The MIPS software used in this study was provided jointly by MicroImages and a grant from the interest on the Creation Research Society Laboratory Fund. The author greatly appreciates the contributions of the donors to this fund and the donations of expertise from MicroImages, Inc. The debris flow expedition in the Grand Canyon was provided by Department of the Interior agencies through the invitation of Bob Webb.

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THE 1993 MIDWEST FLOODS AND RAPID CANYON FORMATION

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Abstract

The processes which creationists postulate may be responsible for rapid canyon formation were vividly demonstrated during the floods which occurred in the Midwest during the summer of 1993. Erosion damage to spillways at three sites is described: Tuttle Creek Lake on the Big Blue River at Manhattan, Kansas; Coralville Lake on the Iowa River at Coralville/Iowa City, Iowa; and Milford Lake on the Republican River near Junction City, Kansas. Each location involved not only the removal of overburden, but also rapid erosion of the underlying strata. Details of duration, water volume, and water flow rates are presented and, where possible, these data are compared to those of prehistoric flood catastrophes. It is shown that extensive erosion in a short period of time is possible even in relatively well-consolidated and lithified strata, and that the pattern of erosion sometimes is remarkably similar to certain features found in the Grand Canyon. Additionally, brief descriptions of strata and fossils are provided.

Introduction

The Creation Research Society has an ongoing project to investigate instances of rapid erosion and to further develop a creationist model for canyon formation. Creationist thinking on the potential for rapid canyon formation has been recently chronicled in this journal (Williams, 1991; Williams, Meyer, and Wolfrom, 1991, pp. 93-97; Williams, 1993). A decade ago Austin (1984) chronicled rapid erosion and canyon formation on Mount St. Helens following the 1980 volcanic eruption. In this paper three examples will be presented showing the erosive power of vast quantities of turbulent water, moving swiftly under pressure, and laden with sediment: Tuttle Creek Lake on the Big Blue River at Manhattan, Kansas; Coralville Lake on the Iowa River at Coralville / Iowa City, Iowa; and Milford Lake on the Republican River near Junction City, Kansas. The Tuttle Creek area will be discussed in some detail later in the paper, but first the two other locations will be briefly surveyed. All three cases provide exceptional opportunities to observe firsthand the conditions which creationists postulate are capable of rapid canyon formation, even in limestone bedrock.

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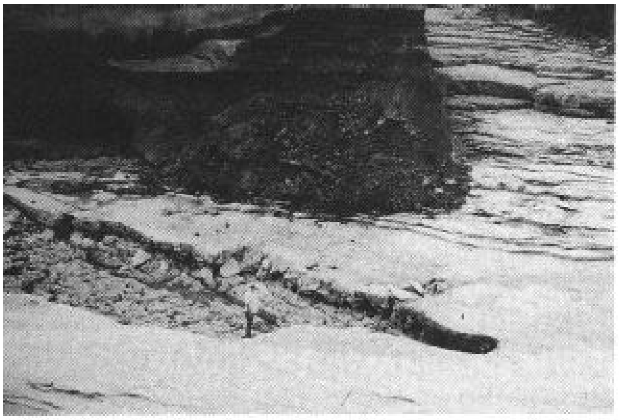
Milford Lake

On 20 July 1993, water began flowing through the emergency spillway of Milford Lake. Three days later the earthen spillway dam and the road atop it (Kansas State Highway 244 Spur) were breached, producing extensive erosional damage as a result of the rushing flood waters (Figure 1). Water flowed through the

1a.



1b.

1c.

Figure 1. Flood damage at emergency spillway of Milford Lake. Photographs by U.S. Army Corps of Engineers. *a.* Photograph taken on 23 July 1993 a few hours before the breach occurred. *b.* Breach in dam (10 August 1993). Note person standing in channel of eroded bedrock near center of photo. *c.* Eroded bedrock above the spillway dam (10 August 1993).

spillway channel for two weeks (through August 3), reaching a peak flow estimated at 19,000 cfs (cubic feet per second) on July 27 (Bierks, 1994).

It is noteworthy that erosion occurred in the spillway both above and below the dam (Figure 2). In the approach channel above the spillway dam, both valley

2a.

2b.

Figure 2. Aerial views of flood damage at emergency spillway of Milford Lake. Photographs by U.S. Army Corps of Engineers. *a.* View downstream during the flooding (25 July 1993). The road indicates the location of the spillway dam. *b.* View upstream after the flood waters had receded (6 August 1993). Again, the road marks the location of the spillway dam.

sediment fill and the top layer of shale (Holmesville Shale) were removed exposing and eroding the underlying Fort Riley Limestone. Of special interest is the pattern of erosion which occurred above the dam. In Figure 2b one can readily see structures which are remarkably similar to side canyons and temples (or buttes) found at the Grand Canyon. Erosion of the limestone continued in the channel below the spillway.

Coralville Lake

Coralville Lake, named for the nearby town which was in turn titled for the area's fossil coral formations (Figure 3), was subjected to the historic floods of 1993 which devastated Iowa and the adjacent midwestern states. Water began to overflow the concrete emergency spillway on 5 July 1993 and continued for a period of 28 days. A maximum estimated flow rate of 17,000 cfs was reached on 24 July following closure of the normal outlet gates for seven hours due to downstream flooding of the Iowa River (Rogers, 1993). The water level in the lake at this time was nearly 4.5 ft higher than the top of the spillway.

Figure 4 provides a view of the resultant erosional damage below the spillway, with the concrete spillway

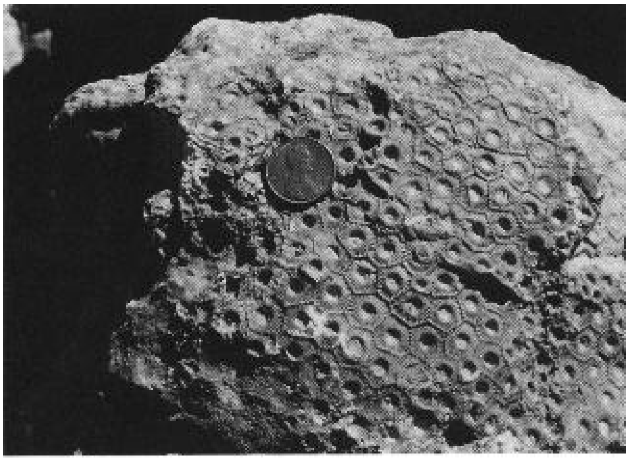


Figure 3. Fossil coral *(Hexagonaria;* Anon., 1993) at Coralville Lake spillway.

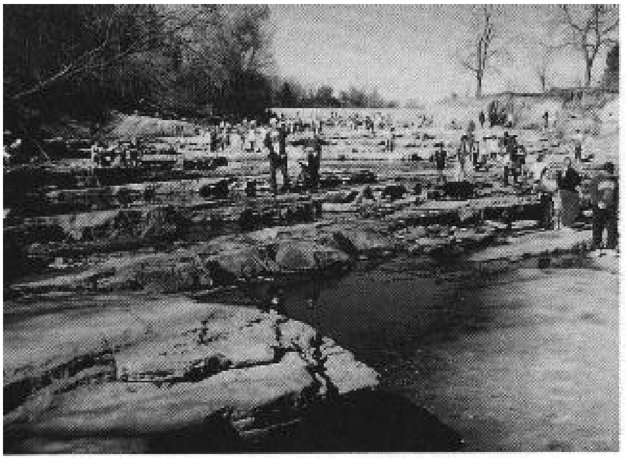


Figure 4. Erosion damage in spillway channel at Coralville Lake. The concrete spillway is visible in the background.

itself visible in the background. A 15-foot channel was eroded into the underlying bedrock (Anon., 1993), exposing limestone which by uniformitarian standards is said to be of Devonian age (viz., some 375 million years old). As is evident in the photograph, a steady stream of visitors (park rangers stopped counting at 150,000) has taken advantage of this rare opportunity to view these rock formations both horizontally and vertically. In addition to the corals mentioned earlier, a number of other fossils could be observed in plenitude, especially brachiopods and crinoid stems (Figure 5). Also observable were fossilized ripple marks and worm burrowings. The public was not allowed to remove materials from the site, but some specimens were excavated for further study by the Iowa University Geology Department.

Particularly impressive was the bony plate from an armored fish (Figure 6) reportedly discovered by a four-year-old boy. Local geologists have identified the creature as the placoderm *Dunkleosteus* (Rogers, 1993), the largest of all Paleozoic animals, having enormous jaws and growing to lengths of 30 ft (Thompson, 1982, p. 759). The armored head shield, hinged at the neck, occupied one-third of the total body length (Anon., 1975). Sometimes called *Dinichthys*, they are reported

Figure 5. Fossil crinoid stems at Coralville Lake spillway. Crinoids (sea "lilies") are marine invertebrates of the class Crinoidea, phylum Echinodermata.

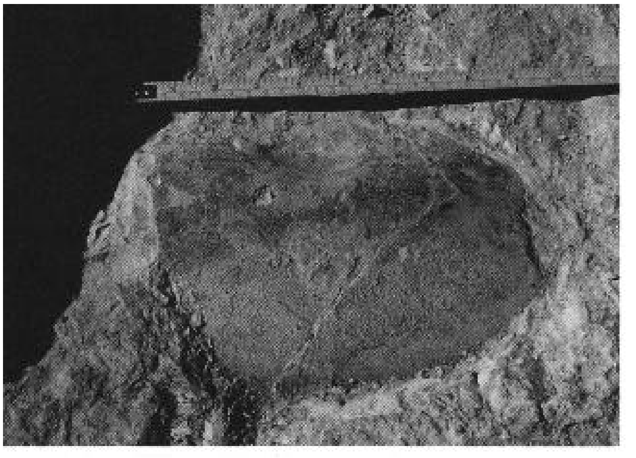


Figure 6. Fossil bony plate from the placoderm *Dunkleosteus* (Rogers, 1993) at Coralville Lake.

to have been common in the Devonian but became extinct at the end of that period.

Tuttle Creek Lake

On a grander scale is the erosion that occurred below the spillway at Tuttle Creek Reservoir when all 18 floodgates were opened (Figure 7). In fact, the area is now referred to as the "Grand Canyon of Manhattan," the "Little Grand Canyon," or simply the "Manhattan Canyon." Kansas State University geologists have stated that the Grand Canyon of the Colorado and the Manhattan Canyon were formed by similar forces (Archer et al., 1993; Blakeman, 1993), but that the recent flood waters "carved out this small canyon much faster than water and wind sculpted the Grand Canyon" (Blakeman, 1993).

Prior to July, 1993, the area below the flood spillway was a gently sloping, grassy recreational area used for dirt bikes. Erosion was initiated in early July when some water was released (10,000 to 25,000 cfs) through the gates just to keep the rising flood waters from running uncontrolled over the top of the spillway (Archer et al., 1993). However, the water level in the reservoir continued to rise, and on 23 July all 18 floodgates were opened, greatly accelerating the erosional processes. In fact, this was the first time since the project was completed in 1962 that any of the gates had been opened. When the gates were closed 17 days later, it was discovered that the landscape of the spillway channel had been transformed into a craggy, variegated, and multilayered canyon. As at Coralville, geologists and laymen have been presented with a unique opportunity to have a horizontal view of thousands of square meters of strata that usually are observable primarily in vertical sections (e.g., roadcuts, hillsides, etc.).

Table I. Daily (0800 hr) Rates of Flow from Tuttle Creek Reservoir*

Day	Outflow (1,000 cfs)	Source
July 17	0.10	Outlet gates
July 18	1.58	⇓
July 19	0.10	⇓
July 20	16.25	⇓
July 21	22.50	Spillway + outlet gates (ca. 5,000 cps)
July 22	26.50	⇓
July 23	44.50	⇓
July 24	55.80	⇓
July 25	60.00	Spillway gates
July 26	60.00	⇓
July 27	59.00	⇓
July 28	58.00	⇓
July 29	57.00	⇓
July 30	56.00	⇓
July 31	54.00	⇓
August 1	53.00	⇓
August 2	48.00	⇓
August 3	46.00	⇓
August 4	43.00	⇓
August 5	38.00	⇓
August 6	34.00	⇓
August 7	30.00	⇓
August 8	25.00	⇓
August 9	20.00	⇓
August 10	15.00	Outlet gates
August 11	15.00	⇓
August 12	15.00	⇓

*U.S. Army Corps of Engineers (1993)

Table I shows data, provided by the U.S. Army Corps of Engineers (1993), giving the flow rate from the reservoir during the period of 17 July through 12 August. The maximal flow rate of 60,000 cfs was reached in the first few days after opening all the gates, and flows greater than 50,000 cfs persisted for more than one week. The maximum flood level above the top of the concrete spillway was higher than a three-story building (31.77 t), forcing 27 million gallons (234 million pounds) per minute, seven million tons of water each hour, moving at about 30 miles per hour (mph) through the gates (Archer et al., 1993). The water from the spillway was not flowing in a smooth or laminar fashion, but rather

> . . . it was turbulent, rolling, rocking, and cutting as it moved, carrying tons of sediment that acted like a chisel, a drill, a grinder, and a thousand bulldozers, all in one. The resulting mass of water hit the loose and poorly consolidated sediment and rocks below the spillway lip like a massive explosion lifting, cutting, and churning its way. . . carrying along hundreds of tons of boulders, gravel, sands, shale, and limestone which it had just torn loose as it roared over the rock surface (Archer et al., 1993).

Table II. Stratigraphic Sequence at Tuttle Creek Spillway *

	Member†	Thickness (ft)	Formation	Group
	:	:	:	
	Morrill Limestone	3.5	Beattie Limestone	
	Florena Shale	7.6		
↑	Cottonwood Limestone	6.9		C
Above spillway		25.4	Eskridge Shale	o
←Spillway gates→	Neva Limestone	17.8	Grenola Limestone	u
Below spillway	Salem Point Shale	8.4		n
↓	‡Burr Limestone	4.1		c
	‡Legion Shale	1.5		i
	‡Sallyards Limestone	2.6		l
	‡	23.3	Roca Shale	
	‡Howe Limestone	4.9	Red Eagle Limestone	G
	‡Bennett Shale	4.0		r
	‡Glenrock Limestone	1.9		o
	‡	23.0	Johnson Shale	v
	‡Long Creek Limestone	7.3	Foraker Limestone	e
	‡Hughes Creek Shale	36.9		
	Americus Limestone	4.2		

* Archer et al., 1993.
† Members are often further divided into zones (U.S. Army Corps of Engineers, 1993).
‡ Rock layers exposed by the flood waters.

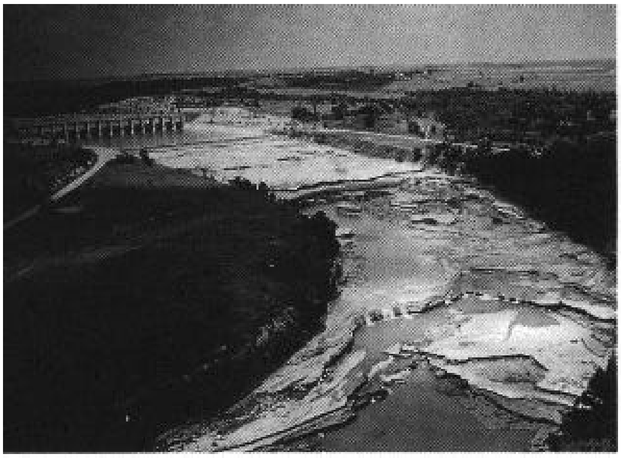


Figure 7. Aerial view of Tuttle Creek Lake spillway area. Photograph by U.S. Army Corps of Engineers.

Figure 7 shows an aerial view of the entire area. The spillway apron itself is approximately 840 ft wide by 580 ft long, and the length of the outlet channel from the top of the concrete apron to the bottom of the photo is about 2900 ft. Figure 8 provides a panoramic view of one of the most severely damaged areas several hundred yards below the spillway (approximately the area in the center of Figure 7). The spillway is to the northwest (left), and additional erosion occurred downstream of the area shown in this photograph. For scale, people walking just below the tree line on the far side of the canyon are barely visible. Structures can be seen which are again remarkably similar to those observed in the Grand Canyon, such as side canyons (alcoves or amphitheaters), caves or undercut ledges, and even temples or buttes within the canyon itself. Figures 9a through 9c, taken at progressively greater distances downstream from the spillway, demonstrate the process and the effects of headward erosion as evidenced by undercutting of the strata.

A portion of the eroded region in the center of Figure 8 is viewed from south to north in Figure 9b. If

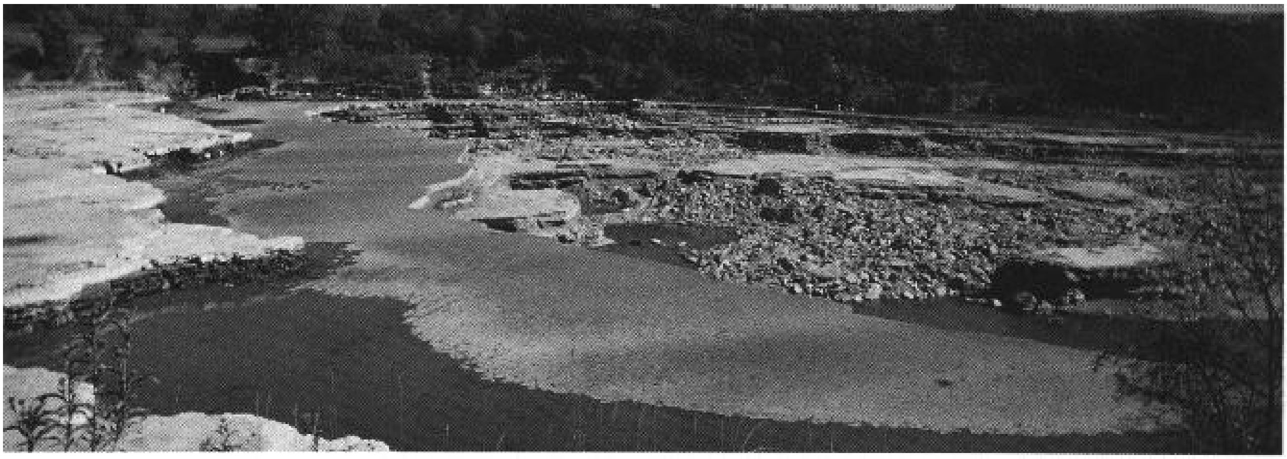
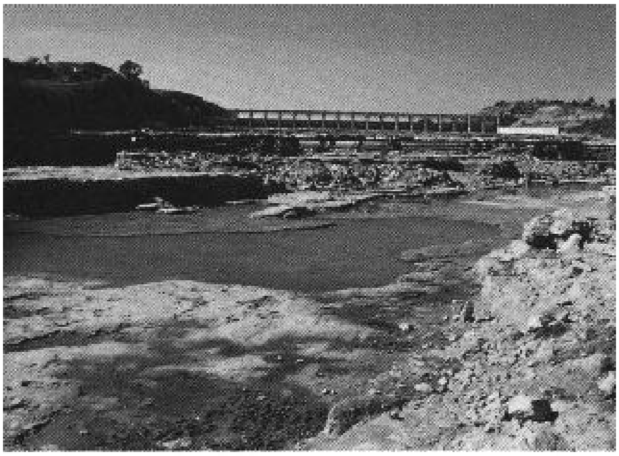
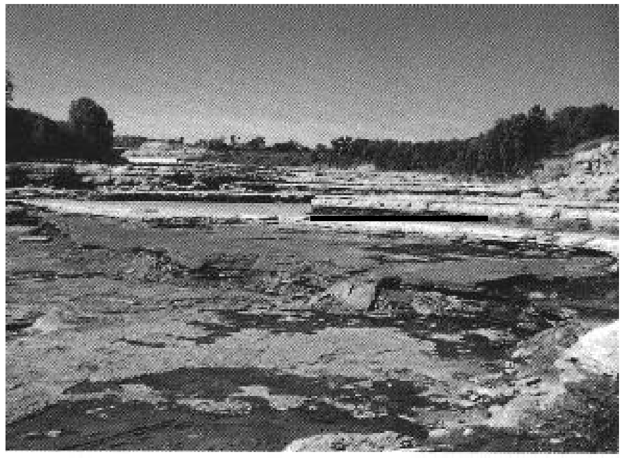
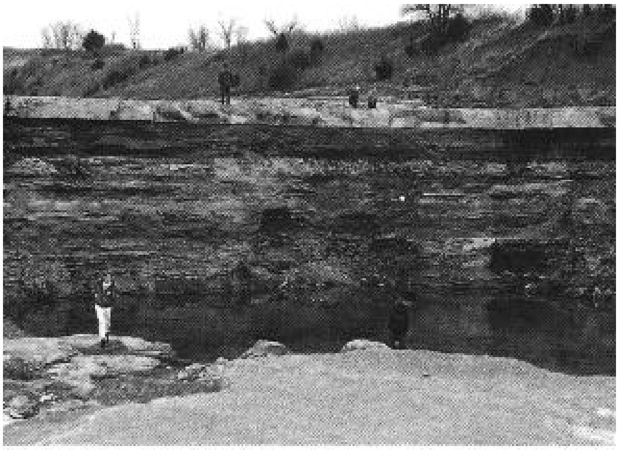


Figure 8. Panoramic view of erosion about 440 yards below apron of Tuttle Creek Lake spillway. People are barely visible walking just below the tree line on the far side of the canyon. Width of the canyon channel at this point is approximately 580 ft.



9a.





9b.

Figure 9. Photographs taken at progressively greater distances downstream from spillway apron: *a.* ca. 500 ft; *b.* ca. 1300 ft; *c.* 2800 ft.

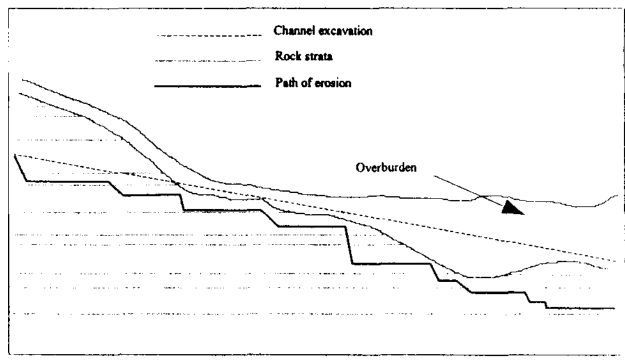


Figure 10. Hypothetical representation of erosion which may occur in a spillway outlet channel.

the person at the top of the ledge is assumed to be six ft tall, then one can calculate that more than 30 ft of lithified materials were eroded away by flood waters at this location alone. In total, from the spillway apron to the base of the hill downstream, nearly 100 vertical ft of rock have been excavated (Archer et al., 1993). However, one will not find 100 vertical ft removed in any one location. The area was already gently sloped and, at the time of construction, overburden and some strata were removed as the spillway channel was excavated. Erosion, following the grade of the excavated channel, was accelerated at various sites due to condition of the strata and the physical processes involved (see below). Based on the findings at the Manhattan

Figure 11. Fossil animal burrows *(Planolites?;* Thompson, 1992, p. 735) at Tuttle Creek Lake spillway.

Figure 13. Fossil shrinkage cracks with camera gadget bag for scale. Tuttle Creek Lake spillway.

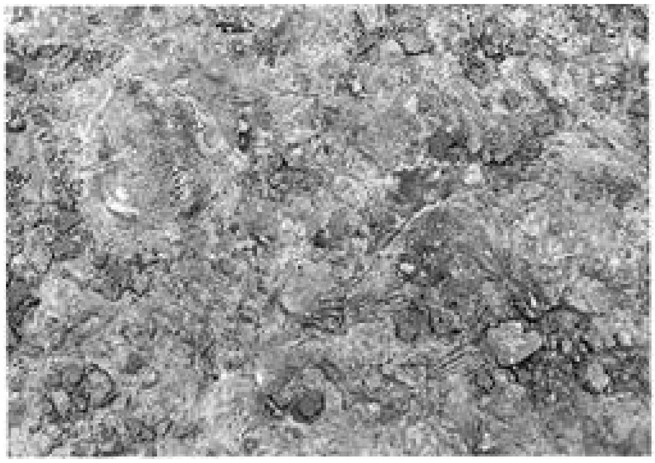


Figure 12. Poorly preserved fossil brachiopods at Tuttle Creek Lake spillway.

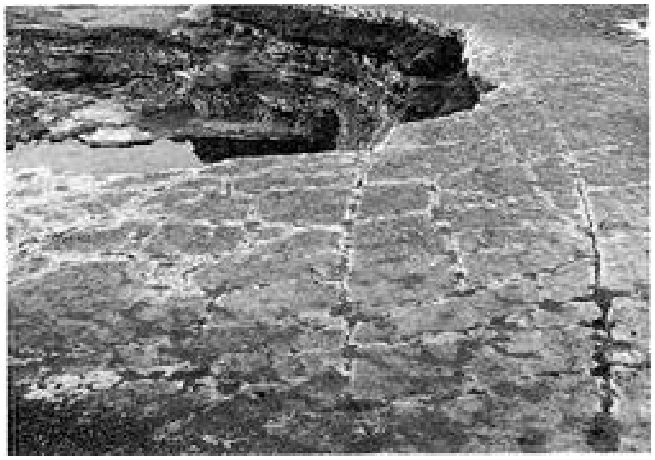


Figure 14. Cross joining of the limestone at Tuttle Creek Lake Spillway. Photographed area is that atop the ledge and to the right in Figure 9b.

site, Figure 10 illustrates a hypothetical representation of erosion in spillway outlet channels.

Geology of the Manhattan Canyon

The strata exposed below the spillway have been identified as Paleozoic, representing late Pennsylvanian through early Permian systems which, in evolutionary time, are represented to be about 290 million years old (Archer et al., 1993). Shown in Table II is the relevant stratigraphic sequence of the area. The concrete spillway itself rests upon the Neva Limestone and the underlying Salem Point Shale. A variety of both invertebrate body and trace fossils may be found in the newly exposed strata (Archer et al., 1993). For example, worm(?) burrows (Figure 11) and poorly preserved "beds" of brachiopods containing thousands of individual organisms may be observed (Figure 12). Also preserved in the strata are what appear to be "mud cracks" (Figure 13). Austin (1991a, pp. 32-33) noted that such structures are more properly known as shrinkage cracks, and cannot be interpreted to be actual mud cracks without further investigation. Shrinkage cracks can result either from extended periods of desiccation prior to burial, or by syneresis of wet sediments after burial.*

One notices the repeating pattern of limestones and shales. Detailed examination of the fossil assemblages associated with these strata suggests that the area was alternately exposed to marine and marginal or nonmarine environments (Archer et al., 1993). Williams and Howe (1993, pp. 51-52) discussed the interfingering of marine and continental sediments in the Big Bend area which may have resulted from tectonic activity during the Flood. For example, the continental area near a shore could sink, allowing marine water and sediments to transgress the region, which in turn could be followed by regression of the marine water allowing additional deposition of continental material. Such patterns of regression/transgression could then have been repeated time and again during the Flood.

*For a detailed discussion of shrinkage cracks, see: Oard, M. J. 1994. Underwater "mudcracks." *CRSQ* 30:213-214.

The Means of Erosion

The rock strata below the spillways at both Coralville and Tuttle Creek are marked by joints (fractures) which represent structural weaknesses (Archer et al., 1993; Anon., 1993). Such joints, which are roughly parallel and may extend through strata for long distances horizontally and vertically, likely contributed to the rocks being ripped away by the fast moving water. Cross jointing of the limestone at Tuttle Creek is illustrated in Figure 14. As alluded to earlier, the erosive action was doubtlessly aided by the velocity of the water and its sediment load which consisted of abrasive matter such as sand, gravel, boulders, etc. Physical processes associated with macroturbulent flow, which contribute to erosion of bedrock during catastrophic flooding, have been elucidated by Austin (1991b, p. 88). These include:

1. Cavitation—a rock pulverizing process resulting from the implosion or collapse of vacuum bubbles (see also Holroyd, 1990a and 1990b)
2. Plucking, or the hydraulic lifting of large blocks of bedrock—a suction process which results from the vortex action of a "kolk"

Could such processes have been active in these cases of rapid canyon formation? Hydraulic plucking obviously occurred, since large blocks of limestone bedrock were scattered haphazardly downstream at both Coralville and Manhattan.

That cavitation may have taken place is not as evident. Holroyd (1990a, p. 24) instanced data from the Bureau of Reclamation indicating that cavitation may occur at fluid flow speeds greater than 30 meters per second (67 mph). Austin (1991b, p. 88) cited NASA data which suggest that cavitation may be associated with fluid flows as slow as 30 ft per second (20 mph). It was in fact earlier noted that water moved down the Manhattan spillway at about 30 mph, suggesting that conditions conducive to cavitation could have existed during the canyon's formation. Figure 15 shows the pitted limestone surface at one particular location in the Manhattan Canyon, which may indicate the effects of cavitation. It is also possible that continued pulverizing and weakening of the rock and subsequent erosive action could obliterate any direct physical evidence of cavitation.

Figure 15. Pitted surface of limestone at Tuttle Creek Lake Spillway.

Table III Comparison of Recent and Prehistoric Catastrophic Floods

Location	Maximum Discharge Rate (cfs)	Maximum Current Velocity (mph)	Volume of Water Released (cubic miles)
1993 Floods			
Coralville	17,000	- -	- -
Milford	19,000	- -	- -
Tuttle Creek	60,000	30	0.00044[5]
Prehistoric catastrophes			
Bonnevllle Flood[1,2,3]	15,000,000	16	380
MissouIa Flood[1,2]	386,000,000	45	500
Allay Mountains, Siberia[4]	>635,000,000	101	240

[1] Conley, 1982.
[2] Maley, 1987.
[3] Malde. 1968.
[4] Baker, Benito and Rudoy. 1993.
[5] Calculated from Table I for July 25 through August 9.

Comparison to Prehistoric Floods

It is interesting to compare these modern flood catastrophes with some prehistoric floods inferred from geologic evidence (Table III). The Bonneville Flood (Maulde, 1968; Conley, 1982; Maley, 1987) occurred when waters of prehistoric Lake Bonneville were catastrophically released into the Snake River Plain, through Red Rock Pass in southwestern Idaho, creating erosional features known as scablands. Carved into the basalt were coulees (or "new" channels, some several miles long and 150 ft deep), alcoves (or dry falls), and rock basins (or potholes) up to 120 ft in depth. Cavitation is thought to have contributed to formation of the alcoves. Large basaltic boulders (10-30 ft in diameter) were transported several hundred miles downstream, and in some areas were deposited in beds up to 300 ft thick.

An ice dam holding back the waters of glacial Lake Missoula during a pre-late Wisconsin glaciation (Flint, 1971, p. 232) was breached, creating a deluge, known as the Missoula Flood (sometimes referred to as the "Spokane flood"), over a 550-mile course across three states (Conley, 1982; Maley, 1987). Carving its way through the basaltic bedrock, the water produced giant ripple marks (detected only from the air some are 20-30 ft in relief, two miles long, and 200-300 ft apart), canyons (miles long and over 200 ft deep), and dry falls. In eastern Washington state the affected 15,000 square mile area is called the "Channeled Scabland." The Grand Coulee, a chasm 50 miles long and 906 ft deep, is thought to have been eroded during this time by cataract retreat, a process similar to headward erosion. Some geologists have recently proposed that during the late Pleistocene epoch Lake Missoula filled every 30-70 years, and a series of 40 or more floods may have taken place in this area.

A cataclysmic flood in the Altay Mountains of Siberia has recently been described (Baker, Benito, and Rudoy, 1993). It too resulted from the rupture of an ice dam on a large glacial lake during the late Pleistocene, and it produced land forms which are said to rival those in the Channeled Scablands of the Northwest. According to Baker et al. (1993), giant gravel waves were developed, requiring water levels greater than 1900 m (6200 ft) for their formation. A huge gorge, measuring 1.2 miles wide by 1,960 ft deep, is thought to have been "cut rapidly by headward erosion . . . in a manner similar to that seen in scabland channel erosion by the Missoula outburst floods."

The geologic effects of these prehistoric floods, manifested in a matter of days, were undoubtedly caused by the same physical processes which created the damage in the 1993 Midwest floods. Readily apparent, however, is the fact that, in both cause and effect, these prehistoric phenomena were many orders of magnitude larger than the modern events described in this article. These prehistoric floods, in turn, would surely pale in comparison to a water catastrophe, or a series of catastrophes, capable of forming the Grand Canyon of the Colorado.

Conclusions

Such examples of rapid canyon formation relate directly to ideas about how the Grand Canyon may have been formed. Creationist and uniformitarian treatment of this topic was the subject of a series of CRSQ articles (Williams, Meyer, and Wolfrom, 1991, 1992a, 1992b). Though many creationists acknowledge that enormous quantities of fast flowing, sediment laden water were likely responsible for the Grand Canyon's formation, the immediate source of such water is a matter of much discussion. Some have agreed that gigantic lakes on the Colorado Plateau, formed perhaps by remnant Flood waters during late-Flood and post-Flood continental uplifting, may have provided the needed quantities of water (Holroyd, 1987, p. 16; Austin, 1988, pp. 50-54; Brown, 1989, p. 83; Austin, 1991b, pp. 86-87; Williams et al., 1992b). Oard (1993), on the other hand, recently presented various geological problems which provide difficulties for this theory.

Austin (1991b), in discussing the breached dam hypothesis, asked, "Could Grand Canyon represent the eroded spillway from gigantic lakes whose dams have failed?" The erosion damage below spillways, as a result of the 1993 midwestem floods, provides further indirect evidence suggesting that the concept, at least, is possible even in relatively well-consolidated and lithified strata. One must also be aware of the potential for canyon formation upstream from a breached dam, as demonstrated at Milford, as well as downstream. In addition to the extent of the erosion observed in relatively short periods of time, the pattern of erosion produced structures which are remarkably analogous to the side canyons and temples found in the Grand Canyon. Is it possible that such features would not result from uniformitarian processes, but can only be produced by catastrophic events? Undoubtedly, creationists will continue to address these and other proposed mechanisms which allow for the rapid, catastrophic formation of canyons.

These sites may afford other opportunities for creationist research into the subject of rapid canyon formation. The further study of exposed fossils, however, will be severely limited by the rapid weathering which began taking place soon after exposure. If possible, additional detailed field work will be conducted in specific areas.

Acknowledgments

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