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A Little Flood Geology

Part IV: The Nature of Flood Geology

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Abstract

Floods are a key category of geologic processes, as presented in Part I. Examples of flood-related projects the author has worked on were presented in Part II. Part III showed that geologic paradigms can have negative effects on field work, sometimes causing evolutionists to miss or ignore evidence for relatively recent, catastrophic, regional-to-global processes. Creationists can become so enamoured with "Flood models" that they can likewise miss evidence of small-scale, slow geologic processes (Part III). Both positions present a false dilemma since both current processes and very different past processes contributed to modern landscapes. In this paper, evidence for megafloods is presented along with peculiarities of scale, evidence for equifinality of disparate processes, and some of the limitations of extrapolating from local floods to megafloods and from regional megafloods to the Deluge. While good analogues are essential, it is also essential to recognize their limitations, especially effects of scale.

Key Words: Flood geology, Megaflood, Equifinality, Evorsion, Landform, Analogue, Scale effects

Introduction

As documented in Part I (Klevberg, 2019), floods are a key geologic process and the largest category of natural disasters. Even small floods can do a great deal of geologic work, as documented in Part II (Klevberg, 2020a) in examples from Central Montana (Figure 1 and Table I). These often combined with mass wasting and ground water phenomena, some very difficult to explain. Part III (Klevberg, 2020b) provided examples of processes acting gradually or stochastically. While these are incapable of explaining larger features of the rock record and landscapes (i.e., uniformitarianism is discredited), they are important on a local scale. Similarly, abundant evidence for mega-flooding should not be ignored by secular geologists. To pit one set of evidence against the other is a false dilemma; the real tension is between geologic paradigms, not science. Flood analogues can be a bridge between geology and natural history. In this part, the knowledge gained from the Montana floods of 2011 is extended to megafloods.

Flood Geology as a Bridge to Natural History

A great deal can be learned from floods, though mysteries remain, even with relatively small floods. This is evident in the difficulties of flood prediction, and

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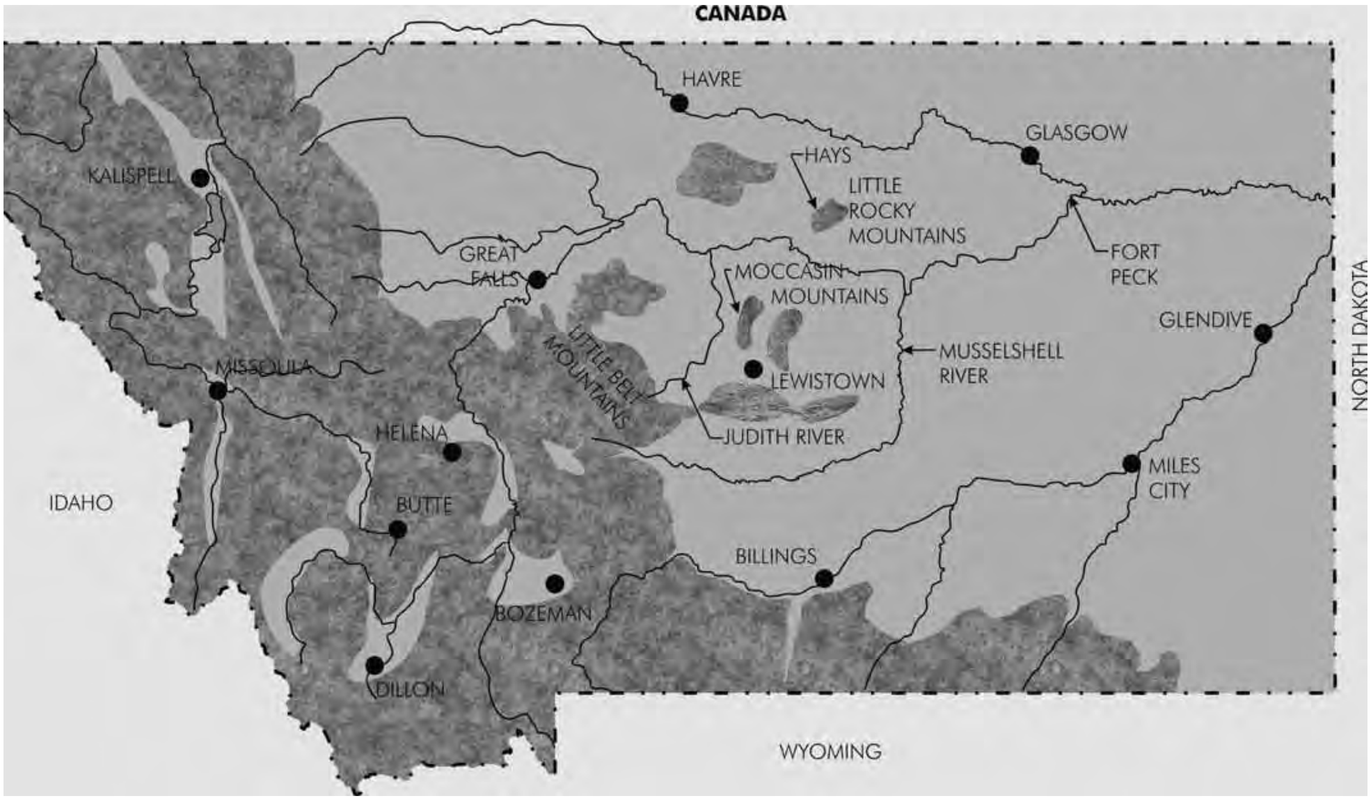

Figure 1. Map of Montana showing major rivers and mountainous areas.

in estimating scour and back calculating flood parameters. To what extent can we extrapolate our knowledge from today's floods to past "megafloods"?

In fluid dynamics, complex phenomena are modeled in wind tunnels and flumes by controlling important ratios (dimensionless parameters) such as Mach number, Froude number, or Reynolds number. This allows a large-scale process to be modeled at laboratory scale under controlled conditions. In geology, processes are observed at small scales, but to what extent can they be validly *extrapolated* to larger scales?

This difficulty is exacerbated when elements of natural *history* are introduced. None of the megafloods listed in Table II (the first five floods in the list) were observed; all of them are inferences from geologic features. They are unique, unrepeatable, historic events, not scientific experiments. It is not possible to turn on a flume and run trials under controlled conditions, or even watch a re-run. This is the essence of why natural history is a "mixed question" (Adler, 1965), and why the level of certainty is less than with direct scientific observation and measurement (Reed and Klevberg, 2018).

Table I. Selected Peak Discharges from 2011 in Central Montana

Gauging Location	Peak Discharge	
	m^3/s	cfs
Musselshell River at Martinsdale	136	4,800
Musselshell River at Harlowton	153	5,400
Musselshell River at Roundup	425	15,000
Musselshell River at Mosby	736	26,000
Judith River at Utica	140	4,960
Judith River at Central Montana Rail bridge	283	10,000
Judith River at mouth	433	15,300
Missouri River downstream of Fort Peck	1,866	65,900

*Data from U.S. Geological Survey

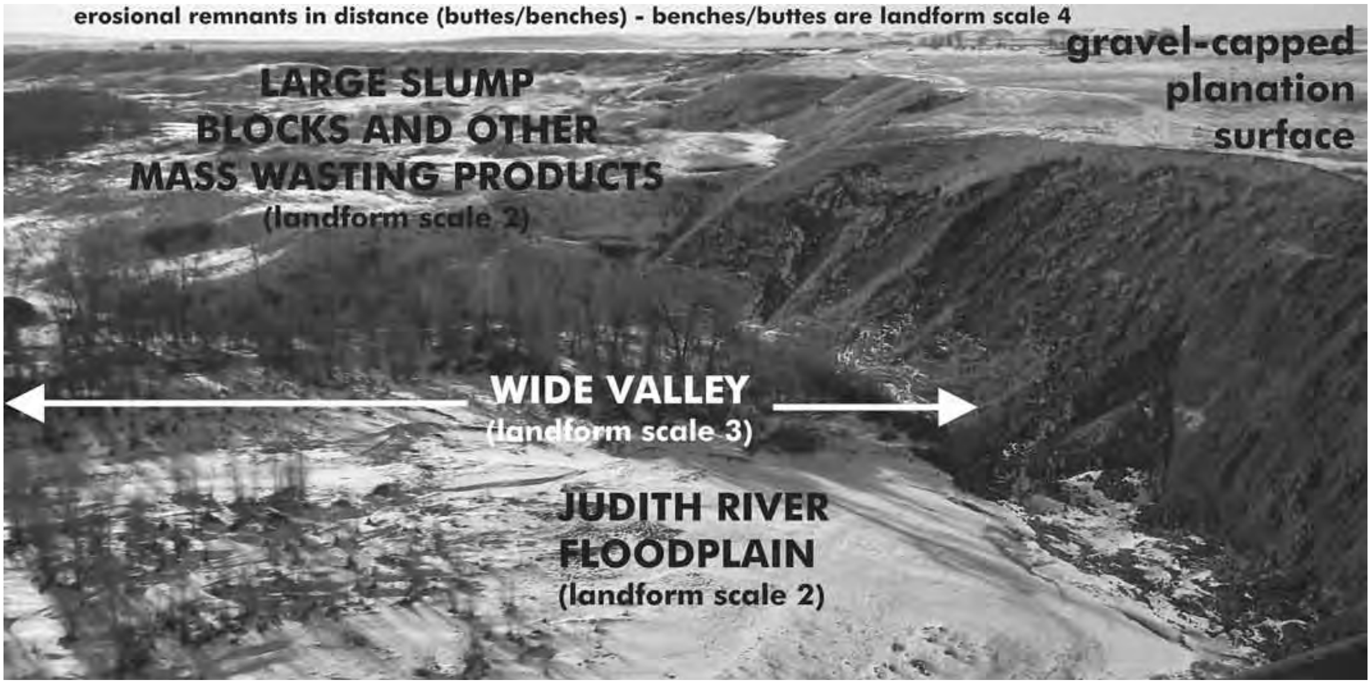

Figure 2. View southwest from near west-northwest end of Judith River bridge. Note that slope instability indicates the valley was formed by processes considerably larger (more catastrophic) than those operating today. Modern processes subdue the topography through mass wasting, which also encroaches on the relict planation surface (bench).

Scale

Some of the problems of scale have been noted relative to prediction of scour (Holnbeck and Parrett, 1997). Many of the physical relationships used in scour analysis were derived from flume experiments. These experiments have proven invaluable, but as the Judith River (Klevberg, 2019, 2020a) showed, the actual scour was significantly more than the initial estimate (prediction), the river being more complex than the laboratory flume. Similarly, megafloods may exhibit much greater complexity.

Geomorphic features

At least four distinct scales are evident in the Judith Basin where Central Montana Rail crosses the Judith River and Arrow Creek (Figures 2–4). The smallest scale (1) is within the stream channel of the Judith River. Based on HEC-RAS computer modeling, the river's 100-year flood plain (2) occupies approximately half of the valley bottom. The edge of the valley (3) is incised into a vast planation surface, or "bench," capped by gravel. The bench edge is marked by a decisively incised slope, with large amounts of mass-wasting products at its base. The bench is approximately 45 m (150 ft.) above the level of the valley and exhibits a scale (4) approximately 150 times larger than the valley bottom. The broad expanse of the Judith Basin consists of a series of closely spaced benches that ramp into each other, with a few higher surfaces remaining as buttes or isolated bench remnants (at the horizon in Figures 2 and 3). These differences in scale are noted in Figure 2.

Both the magnitudes and characteristics of these features show contrasts. The modern Judith River occupies only a portion of the valley floor and is much more sinuous than the oversized valley. This indicates that larger flows eroded this valley. Other than size and the relatively straight form of the valley, its dendritic pattern is typical of streams. The valley is minuscule in comparison to the Judith Basin. The Judith Basin consists of planation surfaces dissected by similar stream courses. As previously noted (Oard and Klevberg, 1998; 2008; Oard, 2008; 2011; 2013), these vast, nearly-level planation surfaces are not *formed* by extant processes; they are being *destroyed* (Crickmay, 1974). The lateral extent of similar surfaces in this region, such as the higher Cypress Hills and Flaxville erosion surfaces, clearly demands extreme processes and energy levels, like those of the Noahic Flood (Oard and Klevberg, 1998). These are extreme processes, unlike the diminutive processes currently in operation, even in the flood of 2011. Table I shows measurements from several Central Montana gauging stations for the 2011

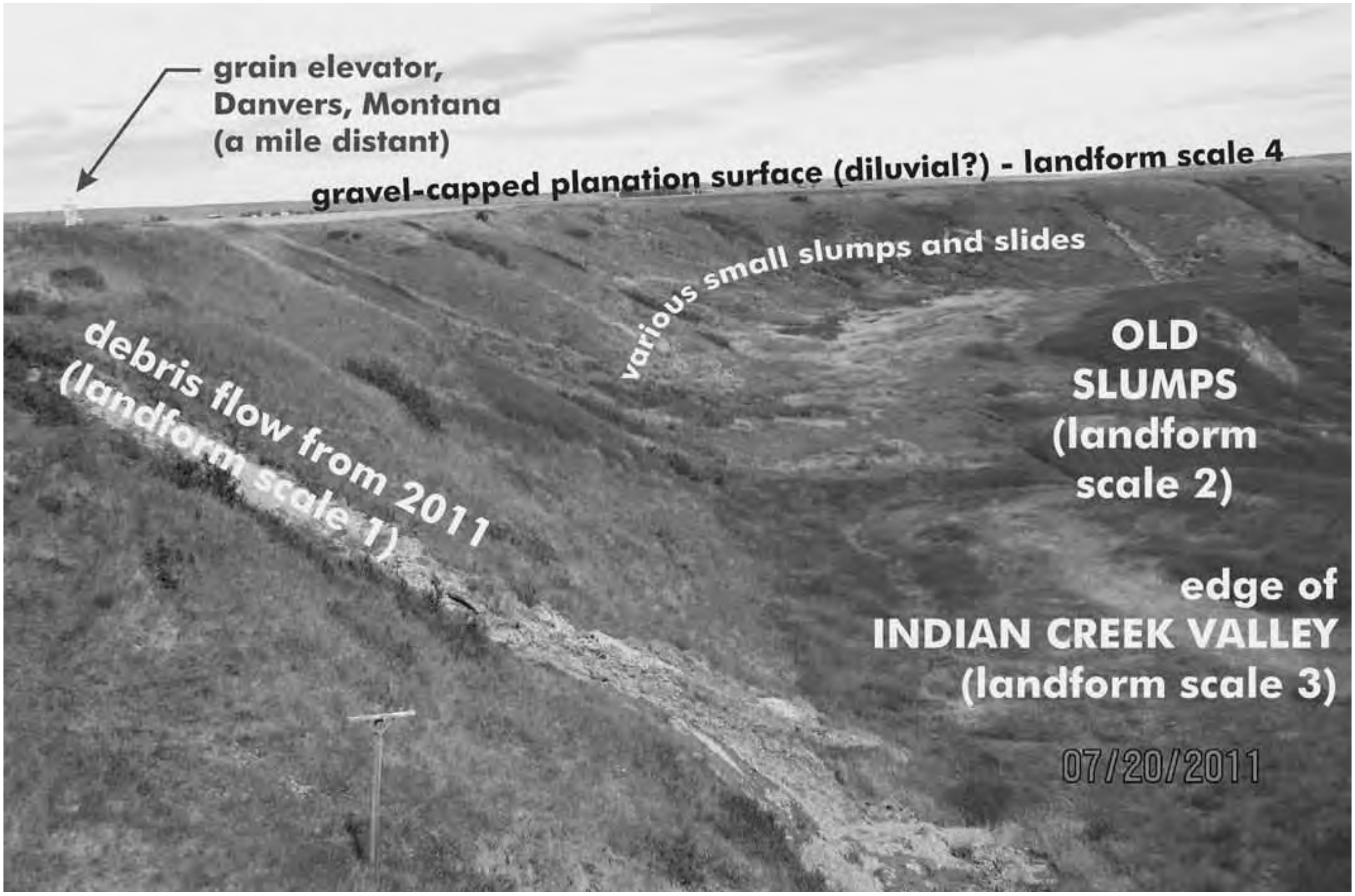

Figure 3. View toward Danvers from west-northwest end of Indian Creek viaduct. Danvers grain elevator provides scale. Mass wasting events of various ages and scales are evident on west side of valley. Extant erosional processes are gradually destroying the gravel-capped planation surface (bench). Such erosion surfaces are not observed forming on earth today (Oard, 2008, 2011, 2013).

flood peak flows. These flows are between one and five orders of magnitude smaller than the megafloods in Table II. Features of the type seen in the Judith Basin do not show evidence of gradual accretion from localized floods, and in scale they defy recognized megafloods. The megafloods themselves are larger than even major floods for which we have contemporary data.

Drainage Basins and Flood Magnitudes

O'Connor and Costa (2003) present data showing an inverse relationship between size of drainage basin and magnitude of flooding events. Cloudbursts dump larger quantities of rain over smaller areas producing more destructive, but localized, flooding (O'Connor et al., 2002). For example, the ghost town of Bannack, Montana's first territorial capital, was severely damaged by a flash flood in 2013, though it escaped such destructive flooding in 2011 and for the 149 years prior. The Bannack flood was localized. The great flood of 1964 ("The Flood" to some locals) in Central Montana remains a vivid memory partly because it overtopped Gibson Dam, initiated the failure of Swift Dam, and resulted in the loss of thirty lives (Department of Military Affairs, 2010), with widespread lowland flooding (Rowell, 2014). However, it was *more* localized in terms of the Missouri Basin than the flooding of 2011 (Alexander et al., 2013). The largest floods in Montana have been a *combination* of factors, typically rain on snow, sometimes ice jams or snowmelt on frozen ground, rather than immediate precipitation (Department of Military Affairs, 2010). In general, 24-hour rainfall amounts in the Musselshell and Judith Basins in 2011 only rated as 10- to 25-year events (Green, 2011).

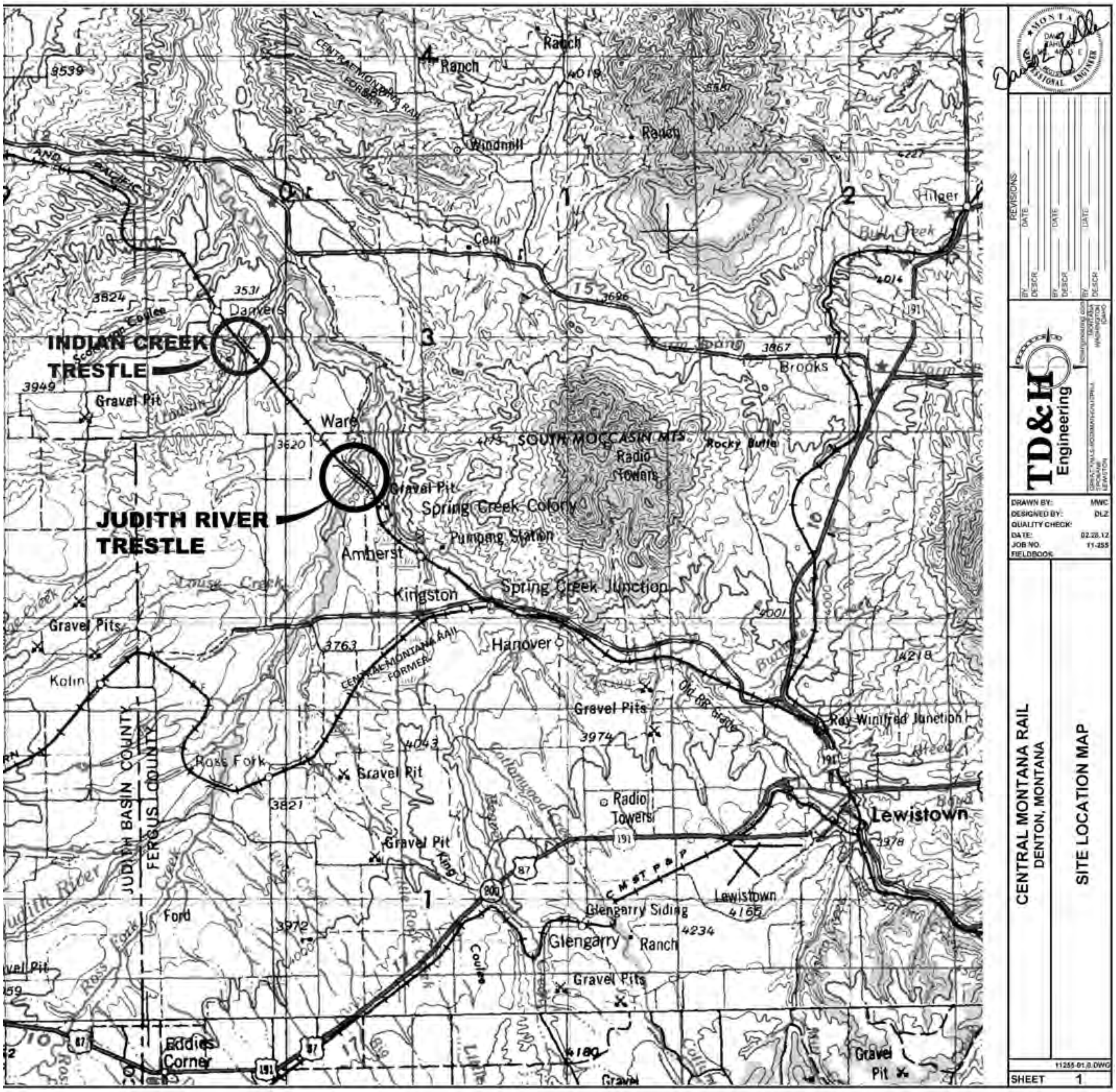

Figure 4. Map showing location of Judith River and Indian Creek bridges northwest of Lewistown, Montana. Figure courtesy of TD&H Engineering.

Extrapolating to Megafloods

To what extent can a flood that does not even inundate a valley bottom be an analogue for a megaflood? To what extent can even "The Flood" of 1964 or the Russell Fjord Flood of 1986 (Q_{peak} = 105,000 m^3/s or $3.7 \bullet 10^6$ cfs) be an effective analogue? While these events clearly demonstrate the episodic nature of the most important geologic processes (Baker, 2002; Benito, 1997; Clayton and Knox, 2007), can they provide quantitative or semi-quantitative means of inferring geologic work?

Table II. Selected Major Floods of the World

Flood	Year	Peak Discharge		Apparent Mode of Initiation	References
		m^3/s	cfs		
Kuray, Altai, Eastern Russia	unknown	1.80E+07	6.36E+08	Ice-dam failure	Rudoy, 2002*
Missoula, Northwestern U.S.A.	unknown	1.70E+07	6.00E+08	Ice-dam failure	O'Connor and Baker, 1992
Darkhat Lakes, Mongolia	unknown	4.00E+06	1.41E+08	Ice-dam failure	Rudoy, 1998
Lake Agassiz, Alberta, Canada	unknown	1.20E+06	4.24E+07	Pro-glacial lake overflow	Smith and Fisher, 1993
Lake Bonneville, Northwestern U.S.A.	unknown	1.00E+06	3.53E+07	Lake-basin overflow	O'Connor, 1993
Indus River, Pakistan	1841	5.40E+05	1.91E+07	Landslide-dam failure	Shroder et al., 1991
Katlahlaup, Katla, Southern Iceland	1918	3.00E+05	1.06E+07	Jökulhlaup	O'Connor and Costa, 2004
Amazon River, Obidos, Northeastern Brazil	1963	2.50E+05	8.83E+06	Rainfall	Rodier and Roche, 1984
Lena River, Kasur, Russia	1967	1.90E+05	6.71E+06	Ice jam and snow-melt	Rodier and Roche, 1984
Yangtze River, China	1870	1.10E+05	3.88E+06	Rainfall	Rodier and Roche, 1984
Russell Fiord, Alaska, U.S.A.	1986	1.05E+05	3.71E+06	Ice-dam failure	U.S. Geological Survey*
Skeiðarársandur, Southeastern Iceland	1996	4.50E+04	1.59E+06	Jökulhlaup	World Data Centre, 1996
Fraser River, British Columbia, Canada	1972	1.40E+04	4.94E+05	Rain and snowmelt	Clayton and Knox, 2007*
Upper Missouri River, North Dakota, U.S.A.	1952	1.40E+04	4.94E+05	Ice-dam failure	O'Connor and Costa, 2004
Glacial Lake George, Alaska, U.S.A.	1958	1.00E+04	3.53E+05	Jökulhlaup	Clayton and Knox, 2007*
Upper Missouri River, Montana, U.S.A.	2011	1.87E+03	6.59E+04	Rain and snowmelt	U.S. Geological Survey*
Upper Missouri River, Montana, U.S.A.	1946	1.44E+03	5.10E+04	Rain and snowmelt	U.S. Geological Survey*
Upper Missouri River, Montana, U.S.A.	1964	4.25E+02	1.50E+04	Rain and snowmelt	U.S. Geological Survey*
Upper Missouri River, Montana, U.S.A.	2014	2.60E+02	9.20E+03	Rain and snowmelt	U.S. Geological Survey*

*Except for these marked sources, information in this table, including sources, is from O'Connor and Costa, 2004.

Missouri River measurements in Montana are from downstream of Fort Peck.

Thankfully, the laws of physics apply at all scales. But is geology just a specialized application of physics (Kravitz, 2013)? Geologists rely on physical analogues, but extrapolation is only valid if the scale does not affect the process. Scale effects include velocity distributions and relative bed roughness. Boundary layer thickness becomes a smaller proportion of flow with deeper water. While the water surface must slope downgradient, the bottom may be quite irregular. The Bernoulli equation still applies. If, however, irregularities of the bottom extend to the surface, flow may be restricted, and a new local base level created. In these cases, an analogy may break down. The most consistent principle is energy: processes will be driven toward lower energy states regardless of scale.

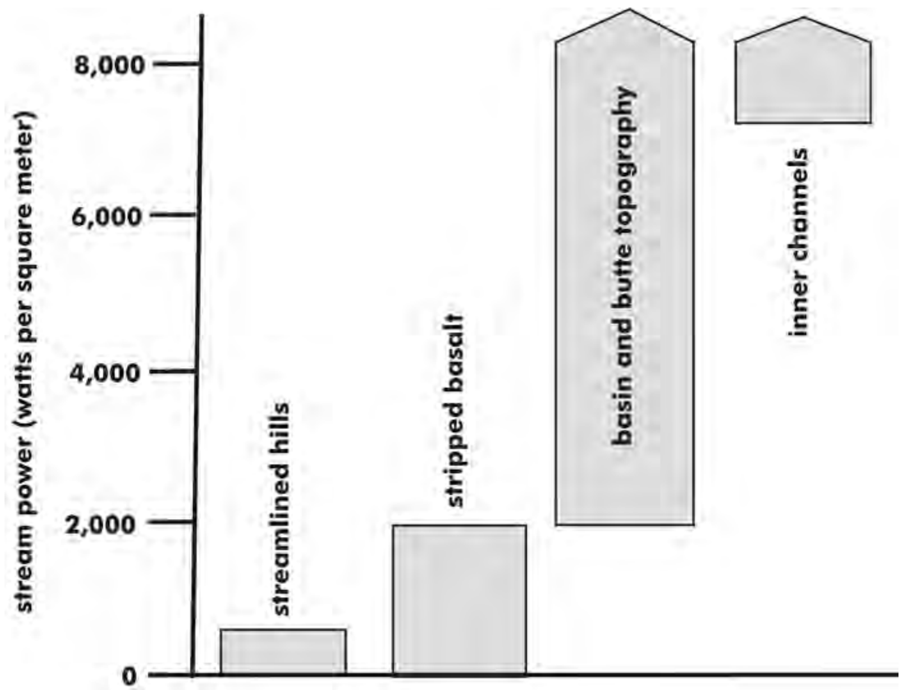

Figure 5. Relation between inferred unit stream power and observed geologic features in the Channeled Scablands along the Columbia River in Washington and Oregon. Figure modified from Benito (1997).

Peculiarities of Megafloods

Megafloods and jökulhlaups (glacial outburst floods) show effects not seen in "ordinary" floods like the 2011 floods. Benito (1997) found a relation between landforms and inferred flow depth for the Missoula Flood (Figure 5). Some of the effects of megafloods not typical of normal flooding are:

- Giant current ripples or antidunes (Thiel, 1932; Carling et al., 2009; Klevberg and Oard, 2016), boulder deltas (Elfström, 1987), giant gravel bars (Benito, 1997; Carling et al., 2009), and large or outsized ramparts and terraces—often errantly called "river terraces" (Rudoy, 2002);
- Deposition of poorly rounded clasts, apparently from suspension (Baker, 2002; Rudoy, 2002);
- Streamlined hills (Benito, 1997) and erosional drumlins (Shaw, 2010);
- Hummocky terrain, diamict(on), and fluting (Shaw, 2010);
- Potholes and closed depressions, butte-and-basin topography (Benito, 1997);
- Grooves and anastomosing (braided) channels (Benito, 1997);
- Oversized valleys and large-scale channels (Kozlowski et al, 2005; Shaw, 2010);
- Giant and erratic boulders (Baker, 2002; Birkeland, 1968; Carling, 2013; Clayton and Knox, 2007; Elfström, 1987; Kershaw et al., 2005).

Each of these could be a fertile area of research, but a few examples are provided here for large boulders. Peculiarly large boulders have been transported in recent history, strengthening the hypothesis that turbulent conditions in the deeper waters of megafloods could move larger clasts than simple application of stream power relations would suggest (Benito, 1997; Kershaw et al., 2005). Boulders a few meters in diameter were moved hundreds of meters by a dam breach flood in British Columbia in 1997 (Kershaw et al., 2005). Boulders up to 5 m (16½ feet) in diameter in Sweden are rounded to subrounded and appear to have been transported 2 to 3 km (1.2 to 1.8 miles) on a low-gradient slope. They have scour marks around them indicative of fluvial transport, probably in a jökulhlaup or high-density flow (Elfström, 1987). A boulder 9 feet long, 5 feet wide, and 4 feet tall (2.7x1.5x1.2 m) was inferred to have been transported in a flood 10 feet (3.3 m) deep in the channel of the Truckee River at about 15 to 18 feet per second (4.5 to 5.5 m/s), and the largest boulder in this study had dimensions of 36 feet by 20 feet by 20 feet (10.9x6.1x6.1 m) where exposed (Birkeland, 1968). The 1928 failure of the St. Francis Dam in California produced a flood with a maximum depth of 125 feet (38 m) and a velocity of 26.4 feet per second (8 m/s); this flood transported a piece of concrete 63 feet by 54 feet by 30 feet

(19.1x16.4x9.1 m) one-half mile (one km) from the dam (Birkeland, 1968). Modern examples of surprisingly large boulders transported over low-gradient slopes are also to be found from various flash floods, though these are dwarfed by the megaflood examples.

Differences between geologic features attributed to megafloods and features from "ordinary" floods can be attributed to processes not found in shallower or lower power floods. Ordinary processes can operate at larger scales. These include *deposition*, where giant current ripples or antidunes, boulder deltas, oversized ramparts and terraces form; *erosion*, forming oversized valleys and large-scale channels, sometimes crossing drainage divides (Clayton and Knox, 2007); and *evorsion* or the formation of potholes by vortices, sometimes at much larger scale than the small potholes found in active streams (Rudoy, 2002). In addition, megafloods and jökulhlaups can produce greater unit stream power or deeper flows with fluid mechanisms unlike normal flood processes, including *cavitation*, where relatively shallow, very rapid flow can produce intense physical erosion of solid rock (Holroyd, 1990; Benito, 1997; Baker, 2002). They also can transport large clasts by suspension in deep, turbulent flow. This may produce coarse, sometimes poorly sorted deposits, and relatively little rounding of clasts (Baker, 2002; Rudoy, 2002; Carling, 2013). In addition, we see evidence of high viscosity or hyperconcentrated flows that may have transported large boulders and produced glacial-like features (Elfström, 1987; Klevberg and Oard, 1998; Shaw, 2010). Finally, we see high unit flow power currents—moderate and deep, energetic currents, could quickly produce scabland and butte-and-basin topography, streamlined hills, and similar features (Benito, 1997; Rudoy, 2002).

All the megafloods in Table II (floods with estimated peak discharges of one million m^3 or more) are "prehistoric." They must be inferred from geologic evidence and are more limited in their usefulness than recent floods that were observed or measured with instruments. The preponderance of these megafloods is believed to have been generated by Ice Age processes quite unlike modern ones (Oard, 1990).

Many unique features of megafloods are simply scale rather than type. For scales common today, many of these are termed "bedforms" and are indicative of the extrapolated flow regimes. Carling et al. (2009, p. 34) recommend distinguishing terminology for these larger, relict features:

> … the term 'landform' is to be preferred as this latter term has neither spatial nor genetic association with a particular portion of a channel way. In a similar sense the adjective 'diluvial' may be a useful precursor to the term 'depositional landform' in as much as the term may be used to signify an association with exceptionally large floods. However, some scientists object to the biblical connotations that the word 'diluvial' carries.

Might there be a little bit of prejudice in the scientific community? Are some features being overlooked because of it?

Flood Prediction

The U.S. Army Corps of Engineers recommends use of megaflood inferences in flood frequency estimation and risk analysis (Fenske, 2003), which assumes uniformitarian history. Megafloods are believed to recur at various times, with an increasing regularity given enough time (O'Connor et al., 2002). This assumption is likewise made in stratigraphy and other branches of geology (Miall, 2013). The consequences of this prejudice should be obvious. Logically, megafloods could have resulted from unusual conditions (e.g., ice age) or could recur in an unpredictable manner. While diluvialists accept a relatively short history for Earth, replete with radical shifts in climate, only recent social pressure from "climate alarmists" might persuade uniformitarians to consider that megafloods may be unpredictable. Even predicting the frequency of modern floods is difficult.

Difficulties with Extrapolation

While extrapolating ordinary stream rates over millions of years per Lyell has been effectively discredited, diluvialists need to be careful as well. As noted by Morris (1976) and others, the Hebrew word for the Deluge is *mabbul* (or *mabbuwl*); not the ordinary word for a flood. One important difference is that many diluvial processes are those of *marine geology*, not *flood geology*. This characteristic of "megafloods" or diluvial processes has been pointed out by several researchers, both diluvialists and uniformitarians. The Altai and Missoula megafloods "... achieved peak discharges ... comparable to the volume of water moved by many ocean currents" (Baker, 2002, p. 2380). Carling (2013) points out the abundance of laterally extensive, planar bedded and often coarse-grained sediments, some with outsized clasts, and sometimes exhibiting a Bouma sequence. He states (p. 104), "This analogy between flood deposits and turbidites is very important as it implies distinctive transport and depositional processes could be at work within megafloods which are akin to density driven processes most commonly seen in the marine environment." While open channel flows are generally applicable by treating the "channel" as having infinite width (Klevberg and Oard, 1998), actual flow during the *mabbul* differed from our understanding of steady, uniform flow and is difficult to estimate. Baker (2002) and Benito (1997) pointed this out regarding the Missoula Flood. As the smaller "megafloods" differ from "ordinary" floods, so a "super-megaflood" or *mabbul* could be expected to differ from "typical" megafloods.

The same difficulty in extrapolation applies to sedimentation in general (cf., Carling, 2013). If we keep these important differences in mind, we can appropriately use knowledge from flood hydrology, flood geology, and marine geology to test natural history speculations. As Kravitz (2013, p. 21) noted, the past cannot be observed: "To state this more exactly, by assuming the uniformity principle, the past becomes dependent on the geologist's thinking, and in this sense, he can be said to construct it rather than discover it." While diluvialists have the advantage of a written historical account, natural history speculations are still natural history speculations.

Conclusions

Accrued knowledge of flood geology from local floods (mostly of rivers) has been extrapolated to megafloods. Observations and inferences include:

1. Most important geologic processes apparently have been (and continue to be) episodic, and floods are an example of such processes, especially megafloods.
2. Most geologic modeling is based on analogues with only limited ability to control conditions using dimensionless parameters (e.g., flume experiments). Field analogues, such as "ordinary" floods, must be *extrapolated* to megaflood scale. Extrapolation is only valid if *scale* does not affect the process.
3. Megafloods (>10^6 m^3/s) have not been observed but are inferred from geologic features that resemble what one would expect. Evidence of megafloods has been observed in many places.
4. Extrapolating from flume-scale controlled conditions to river-scale uncontrolled conditions is valuable but incomplete, since "real world" conditions can be much more complex. This has been illustrated by difficulties in accurately predicting scour.
5. Megafloods produce many of the same features and landforms as "ordinary" floods, though often at much larger scales. These include giant current ripples or antidunes, boulder deltas, and outsized ramparts and terraces.
6. Megafloods also produced landforms and features not commonly observed today, including deposits of poorly-rounded clasts, streamlined hills and erosional drumlins, hummocky terrain, diamict(on), fluting, potholes, butte-and-basin topography, and large erratic boulders. Some of these features are common with glacial processes (i.e., equifinality).
7. Geologic formations and landforms observed in the Judith Basin of Montana do not show evidence of gradual accretion from local floods. The scale of the main valleys suggests megafloods, and the basin's planation surfaces defy gradual processes in scale.
8. Care must be exercised in extrapolating modern flood processes. As megaflood effects appear to be more varied than features and deposits of "ordinary" floods, the Deluge would produce more varied features and deposits than later megafloods. In many cases, megaflood (and particularly diluvial) processes may be more accurately thought of as *marine* geology rather than *flood* geology.
9. While historical geology is a "mixed question" that properly belongs in the category of natural history, it has long been viewed as natural science by uniformitarians. Geology as a science has contributed much to our understanding of erosion and deposition, especially through flood studies, and it has discredited uniformitarian philosophy. Nonetheless, uniformitarian thinking still dominates the geologic community.
10. Common flood prediction methods are based on commitment to belief in traditional "deep time." This paradigm may produce false confidence in our ability to predict the magnitude and frequency of floods. Climate change may further complicate this and limit our ability to predict flood events.

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