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THE POTENTIAL FOR AND IMPLICATIONS OF WIDESPREAD POST-FLOOD EROSION AND MASS WASTING PROCESSES

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ABSTRACT

Post-Flood geomorphology was greatly affected by factors such as the connate water content of sediments, degree of lithification, volcanic activity, seismic activity, tectonic activity, precipitation, lack of vegetation, and various glacial processes. These factors and others greatly enhanced the potential for various types of erosion and mass wasting following Floodwater withdrawal from the continents on scales from minutes to millennia. Creation geologists have yet to realize the impact these processes could have played in shaping our present-day landscape; in geomorphic models proposed thus far, shaping happened by direct retreat and erosion of the Flood water itself. During the immediate post-Flood times (irrespective of where one places the Flood/post-Flood boundary) these factors would have contributed to immense continental denudation (and deposition), destroying (or burying) surfaces eroded during Floodwater retreat. The implications of these factors need to be included in post-Flood modeling and the development of young earth geomorphology models. While the focus of this paper is on denudation processes, insights into these processes will help us to better understand post-Flood depositional processes and the potential sediment sources and mechanisms for filling deep post-Flood basins, deposition of giant deltas and the formation of thick post-Flood blankets of sediment on the seafloor, for example.

INTRODUCTION

In Flood models developed thus far, very little has been written on what geomorphic processes might happen as the continents emerged from the Deluge and Noah left the Ark. In the *Genesis Flood* Whitcomb and Morris (1961) talked little about specific post-Flood geomorphology with the exception of “swollen streams” in the Pliocene (p. 286). They did mention volcanic, orogenic and glacial activity that probably occurred in post-Flood times, but did not comment on the possible geomorphic implications of uplifting freshly deposited water-filled rock and sediment. The *Genesis Flood* put forth the paradigm that most geology is explained by the Flood, with very little geomorphic change occurring since then. In the past decade or so, Michael Oard has been the main creationist author on geomorphology. He argues that things like planation surfaces, pediments and water gaps were shaped just prior to and during the emergence of continents from the oceans *before* the Flood was over (e.g., 2008). According to Oard, even features like the Grand Canyon were formed as the continents emerged in the final days of the Flood (2010c), not afterwards. Like Whitcomb and Morris, he envisions no processes capable of creating major geomorphic change after Noah gets off the Ark. Major catastrophism was essentially over at the end of the Flood.

Oard, like Whitcomb and Morris, argues that Flood deposits extend to the Pleistocene boundary (late in the Cenozoic) and that rock layers like the Green River Formation were made during the Flood (Figure 1). Some Creation scientists still hold to this view today, but the consensus among Creation geologists appears to be that the Flood/post-Flood boundary probably lies at the bottom of the Tertiary, at the "K-T" boundary (*e.g*., Austin *et al*., 1994; Whitmore, 2006a, 2006b, 2006c; Whitmore and Garner, 2008; Wise, 2009) or slightly above in some cases (Snelling, 2010).

The goal of this paper is to establish the likelihood and implications of widespread post-Flood erosion and deposition in the time period following the Flood. In doing so, I hope to address a criticism of my past work by Oard. He estimates up to 600 m of material was widely removed in the Green River Basin of southern Wyoming (2006a) and up to 4-5 km was widely removed (including the Green River Formation) in the San Rafael Swell area of Utah (Oard and Klevberg, 2008). He envisions the only way to explain this massive erosion is by retreating Flood waters, thus forcing a Dulivial interpretation on everything older than the erosional surface. This includes formations like the Green River Formation whose sedimentology, stratigraphy and paleontology can best be understood as a post-Flood deposit (Whitmore, 2006a, 2006b, 2006c; Whitmore and Garner, 2008; Whitmore and Wise, 2008). Oard believes that Cenozoic formations, like the Green River Formation, must be Flood deposits because the Flood provides the only mechanism to deposit and significantly erode them in a short period of time.

It should be noted that this paper takes the approach that most of the rocks classified as "Cenozoic" are post-Flood ("Cenozoic" is defined by suites of fossils contained within various formations) and that the Ice Age happened well after the Flood was over, during "Pleistocene" times. The author has studied various other views, but believes that this is the most sensible approach at the current time (Whitmore and Garner, 2008). The denudation arguments presented in this paper should apply irrespective of where one places boundary—whether at the K-T or at the end of the Tertiary. Accordingly, the evidence of that denudation should be present in the rock record in the form of an extensive unconformity lying on top of Flood sediments, followed by thick post-Flood deposits.

POST-FLOOD MASS WASTING PROCESSES

This paper is not a comprehensive treatment of all the post-Flood processes that may have been in operation causing catastrophic denudation. It is also important to recognize that some of these processes may have been more important in some areas and times. For example, glacial floods would have only been important near areas of glaciers (during the Ice Age) and relatively unimportant in areas thousands of kilometers away from them. Seepage pressure in water saturated sediments was probably more important soon after the Flood than centuries later. Following is a list of processes which had the potential to cause massive erosion in the decades and centuries following the Flood. While the focus of this paper is on erosional processes, it should be understood that massive erosion also leads to massive deposition. Thus, thick post-Flood deposits would be expected from massive post-Flood erosion, regardless of where one places the post-Flood boundary.

Seepage pressure in water saturated sediments

Sediments in the immediate post-Flood world would have been water saturated due to the simple fact that they were deposited by water during the Flood year. When sediments are water saturated, sedimentary grains are buoyed by water and the strength of the sediment or rock mass is reduced (Bloom, 1998, p. 170). Water saturated rocks and sediments have been one of the key factors in instigating many types of mass movements (landslides, mudflows, slumps, etc.) like the 1983 Thistle slide in Utah, the 1964 Turnagain Heights slide in Alaska, the 1963 Vaiont slide in northeastern Italy and the 1925 Gros Ventre slide in Wyoming (Hyndman and Hyndman, 2006). Water saturation (because of buoyancy) lowers the energy required to initiate the movements. It is unknown how long it took connate Flood water to sufficiently drain out of Flood sediments; but potentially this could have been an important factor for centuries or millennia. Water saturated sediments are more apt to fail than those without water. Some may argue that Flood sediments were already lithified at the end of the Flood and therefore this process may not have been important, but this argument is mute because some Flood sediments still remain poorly lithified today, more than 4,000 years later. Water saturation is important whether the materials are lithified or soft; modern landslides of lithified sediments are certainly evidence of that. Certainly as continents were lifted out of the Flood waters, giant failures (exponentially larger than those we have historically observed) aided by water in sediments would have occurred, especially around the edges of the uplifted masses. Potentially we should think of entire mountain ranges, high standing crust and plateaus sliding-- perhaps producing some of the “detachment faults” and the various large “thrust” faults and fold belts (especially in unlithified sediments) that are ubiquitous in many areas in the proximity of high relief today. Of course these processes would have happened during the Flood too, but I’m arguing that they would have been significant in post-Flood times as well.

Water saturated sediments could have been more easily eroded by rivers that began to flow after the Flood because of groundwater sapping. Immediate post-Flood sapping would have been very effective because of the high connate water content of the sediments. The results of sapping in unlithified sand can easily be seen due to down-dip flow of water along the edge of a small stream (Figure 2). As rivers (and other processes) cut deeper into the post-Flood landscapes, sediment and rock filled with connate water could have easily been removed by sapping. When draining water is sufficient enough, the sapped material can also be carried downstream (as in Figure 2) efficiently by various mass flow processes. Sapping would not only have dramatically widened post-Flood valleys, it would have greatly lengthened them as well. It is generally agreed that present-day sapping processes can cause amphitheater-headed canyons in lithified rock (Laity and Malin, 1985) as groundwater flows down-dip. But this idea has been recently challenged by Lamb and his colleagues (2006) claiming large surface runoff might be responsible instead. Regardless, it seems reasonable that most post-Flood sediments were only partially lithified immediately following the Flood and highly susceptible to sapping processes when down-dip relief was present.

Precipitation rates, large storms, hypercanes

Both biblical and geological evidence suggests precipitation rates after the Flood were likely much higher than they are today. The early post-Flood account of Abram and Lot observing the green plains in Genesis 13 is suggestive that the Middle East had higher precipitation rates in the past than it does today. Large lakes used to occupy many of the basins in the now dry Basin and Range Province of the western United States. Lake Bonneville alone used to cover almost one third of the State of Utah. Significant amounts of precipitation would have been needed to keep these lakes full of fresh water. Considering that the post-Flood oceans were probably very warm; it has been suggested that world precipitation rates were overall higher and that large storms and possibly hypercanes (super hurricanes with horizontal wind speeds greater than 300 mph) were prominent in post-Flood times, probably supplying the needed moisture for glaciers to form rapidly (Oard, 1990, 2004a; Vardiman, 2003, 2010). If large storms and hypercanes developed after the Flood, they would have had significant erosional and depositional consequences, especially in light of the other factors discussed in this paper. Vardiman (2003, p. 26) discusses the potential post-Flood damage of hypercanes:

> For every doubling of wind speed, the damage is quadrupled. Most damage and loss of life from hurricanes is actually caused by the storm surge, a buildup in water depth as a hurricane sweeps water toward a coastline. The flooding of coastlines by surges 20-30 feet deep from typical hurricanes could be increased many times over by *hypercanes* which would be many times larger and more intense.

> It seems likely that the presence of large regions of warm sea-surface temperature during and immediately following the Genesis Flood would have caused many *hypercanes* to have occurred over the oceans and to have made landfall on the eastern side of continents in the subtropics. These *hypercanes* would have probably been particularly frequent and intense above mid-ocean ridges where significant quantities of heat would have been released. When these *hypercanes* made landfall, they would have dumped massive quantities of rain on as-yet unconsolidated sediments and produced incredible amounts of erosion. Storm surges would be devastating to the coastal boundaries. The most likely location for *hypercane* landfall and such erosion would have been on the eastern edges of continents between about 10˚ and 40˚ latitude. Several heavily-eroded regions on the eastern side of continents could possibly be explained by this process. For example, the heavily-eroded Appalachian Mountains in the eastern U.S. and in Southeast Asia may have been rapidly eroded by hypercanes...

Whitmore, Strom and Faulkner (2010) suggested the large sand dunes on the east coast of the United States in the Carolina Sandhills are actually subaqueous sand waves deposited by hypercanes after the Flood. This is in the prime area where such deposits might be present, according to Vardiman (above). The sediments are angular, poorly sorted and contain large muscovite flakes suggesting rapid erosion and minimal transport from the igneous rock source.

In places where a large amount of precipitation is occurring today, deep canyons can be found nearby. For example, one of the highest annual recorded precipitation rates in the world is 460 inches (11.7 m) from Mt. Waialeale on the Hawaiian Island of Kauai (see http://www.ncdc.noaa.gov/oa/climate/globalextremes.html#highpre). It's probably not a coincidence that Waimea Canyon, the deepest canyon in Hawaii, is just to the west of Mt. Waialeale with a length of 14 miles and a depth of 2500 feet (Hazlett and Hyndman, 1996); an amazing canyon for such a small island with no large streams. Canyons have been noted to form quickly due to modern erosional processes (Froede, 1996; Williams, 1995); post-Flood canyon formation due to high precipitation rates and poorly consolidated sediments should have been even more dramatic.

It is thought that most of the erosion on the Hawaiian Islands has not been due to stream activity, but solution of the volcanic rock by naturally occurring acids, enhanced by high precipitation rates (Hazlett and Hyndman, 1996). On the windward (rainy) side of the Big Island, lava flows only decades old show extensive weathering and soil development, while lava flows hundreds of years old are still "fresh" on the leeward (dry) side of the island (Figure 3). Likewise, canyons are much deeper on the windward side showing the effect of increased weathering due to higher amounts of moisture.

During the time between the Flood and the height of the Ice Age (at least until Genesis 13), the earth has probably experienced much greater precipitation rates that we have today. Where snow was falling at high latitudes forming glaciers, rain would have been falling at lower latitudes forming lakes. The Pleistocene lakes of the western United States (which are post-Flood in all models) would have been filled by these increased precipitation rates (Oard, 2004a, p. 42).

Landslides, tectonic denudation, seismic and volcanic activity

It has been documented that erosion is greatest in areas with the most intense tectonic activity (Dadson *et al*., 2004). These are often areas of high elevation and great relief. The greatest historical mass movements have occurred in areas that have combinations of mountains with high relief and seismic activity. For example, the 1970 Peruvian earthquake (7.7 on the Richter scale) triggered a 50 to 100 million m^3 landslide from Mt. Nevados Huascarán, the highest mountain in Peru. The landslide tragically buried tens of thousands of inhabitants from several villages (Hyndman and Hyndman, 2006). Large landslides have been triggered during most of the largest historical earthquakes including the 1960 Chilean quake and the 1964 Alaskan quake (Austin, 1984). It is thought that earthquake intensity and frequency has been exponentially decreasing since the time of the Flood (Austin *et al*., 1994), thus mass wasting events were likely larger and more common in the years immediately following the Flood.

There are several common triggers for landslides. Landslides often occur in areas of steep slopes and great relief. In these areas factors like heavy rain, excess moisture and/or seismic activity can often trigger a landslide. In looking through a USGS list of the greatest landslides of the 20th and 21st centuries (http://landslides.usgs.gov/learning/majorls.php) earthquakes and heavy rain are the most common triggers (approximately 80% of the total). As new mountains were uplifted after the Flood and subjected to higher rates of precipitation, we might expect the great erosional changes from landslides in mountainous areas.

The largest landslides currently known on earth have originated from volcanos on the Hawaiian Islands and spread out onto the seafloor. Moore *et al*. (1989) describe some astounding statistics of these slope failures which are exposed over 100,000 km^2 on the seafloor around the islands with some of the individual debris fields being more than 200 km long and 5,000 km^3 in volume. Some individual blocks are up to 29 km long and 1.6 km thick (Hazlett and Hyndman, 1996). By comparison, the Mount St. Helens slide (the largest historical slide observed by man) was only 3.7 km^3 in volume (Lipman and Mullineaux, 1981)! Slope failure on the Hawaiian volcanoes probably occurred from a combination of factors including seismic activity and dike injection along rift zones (Lipman et. al, 1988). The Pleistocene timing of these slides would have placed them within the post-Flood era of all Flood models. Probably one of the reasons that we can still recognize these great slides is that they are preserved underwater and have not had surficial processes at work to modify them. Recognition of these types of slides in terrestrial environments has been difficult in the past, and when catastrophic conclusions are reached they are often very controversial (like the conclusions of Heart Mountain drawn by Pierce, 1987).

Rugg (1990) has suggested, based on geological evidence, that the mountain ranges along the Arizona-California-Nevada border are the result of large such catastrophic landslides with displacements up to 80 km. The lower contacts of these slides are known as “detachment faults.” The Tertiary timing of these events would have placed them into the post-Flood period (Figure 1) of my model, although Rugg appears to think they occurred late in the Flood. When using suites of criteria to test for the location of the Flood/post-Flood boundary it appears the faults Rugg studied along with the Heart Mountain and South Fork events in Wyoming, happened after the Flood (Whitmore and Garner, 2008).

Tectonic activity (mountain uplift) has formed many structural basins in the western United States. Many of these basins filled with lake sediments in post-Flood times. It has been documented that some of these basins filled and then catastrophically overflowed. For example, Lake Bonneville in Utah filled and breached its northern boundary deepening the Snake River Canyon (Malde, 1968). Due to the large number of tectonic basins found in the Basin and Range Province of the western United States, it is likely this was a common phenomenon. Basin overflow hypotheses have been around for a long time to explain canyons like the Grand Canyon (Austin, 1994; Blackwelder, 1934). Although the erosion of the Grand Canyon is a complex topic and probably cannot be explained by a single model, basin overflow is being reconsidered by conventional geologists for both the upstream and downstream courses of the Colorado’s canyons (Young and Spamer, 2001).

We know that drastic landscape changes can happen with volcanic activity. The favorite Creationist example is Mount St. Helens, but many other volcanoes could be chosen as well. The entire north face of Mount St. Helens slid away on the day of the eruption in 1980 (Lipman and Mullineaux, 1981) and catastrophic mudflows formed canyons overnight in the years following the eruption (Austin, 2009). The Heart Mountain and South Fork slides are excellent examples of tectonic denudation that originated from the volcanic and tectonic activity that was occurring in the Yellowstone area shortly after the Flood. Large mountain masses slid tens of kilometers before they finally came to rest in the Cody, Wyoming area (Clarey, 2012, 2013 (this volume); Pierce, 1987). It is thought that volcanic and seismic intensity and frequency has been exponentially decreasing since the time of the Flood (Austin, 2010), thus mass wasting events were likely larger and more common as a result of these processes in the years immediately following the Flood than they are today.

Faulting brings along with it the added potential of mass wasting initiated by seismic activity. If the faults are vertical, additional relief adds to the mass wasting potential. For example, it is estimated that about 10 km of vertical movement occurred along the Teton Fault in Wyoming, creating an adjacent basin filled with about 5,000 m of Cenozoic fill (Smith and Siegel, 2000).

Job spoke of seismic and tectonic activity that appears to refer catastrophic to post-Flood events:

> It is God who removes the mountains, they know not how,
> When He overturns them in His anger;
> Who shakes the earth out of its place,
> And its pillars tremble; Job 9:5-6 NASB

Immediate post-Flood rivers were out of equilibrium

Geomorphic theory suggests rivers tend to erode (or deposit) until they reach a “graded” profile as long as they are flowing on “adjustable” materials (Bloom, 1998). The further they are from grade the higher the rates are. In immediate post-Flood times one could imagine that landscapes were significantly “out of grade” because of recent tectonic uplift to raise the continents from the Flood waters. Additionally, poorly consolidated sediments could be considered to be very “adjustable.” Considerable erosion (and deposition) by rivers could be expected until graded profiles were reached. Additionally, tectonic activity and isostatic adjustment would probably continue to radically change river profiles, throwing them out of grade, leading to further erosion and deposition. Combined with higher post-Flood precipitation rates and drainage from water-saturated sediments, rivers would have been much larger than those we find today.

Ice sheets and Ice Age floods

Most Creationists are well aware of the now famous Missoula Flood which created the Channeled Scabland of eastern Washington (Bretz, 1969; Oard, 2003) with canyons up to 300 m deep. It is now well documented that massive floods like this (referred to as “megafloods”), coupled with intense continental and alpine glaciation caused tremendous alteration of the landscape. These floods were widespread and frequent (*e.g*. Austin and Strelin, 2011; Burr, Carling, and Baker, 2009; Herget, 2005; Martini, Baker, and Garzón, 2002). Evidence of these floods has now been found on most of the continents and they have been significant in influencing the geomorphology of vast continental areas in the United States, Canada, the English Channel, central Asian mountains, Iceland and South America. Baker (2013) has documented more than 50 such megafloods (defined as flows greater than 1,000,000 m^3/sec) occurring during the Quaternary.

In some cases flooding was the result of ice dam failure which held back a large lake, as in the Missoula Flood. In other cases the thick and heavy continental ice sheets caused isostatic depression which allowed water to accumulate in depressions under and around the ice. Occasionally, these lakes would drain into massive spillways like the St. Lawrence Seaway and the upper Mississippi River Valley. Ice sheets and Ice Age floods have completely modified the geomorphology wherever ice sheets existed. In fact, the geomorphology of these areas continues to be slowly modified as isostatic rebound has not stopped. Megafloods have produced deep canyons, huge valleys now occupied by misfit streams, gravel bars with thicknesses of 100's of meters, large deltas, high terraces, and many other features inexplicable by ordinary alluvial processes. These floods have greatly modified the geomorphology where they have occurred.

Job, who likely lived during the time of the Ice Age, describes turbid streams as the result of melting ice:

> My brothers have acted deceitfully like a wadi,
> Like the torrents of wadis which vanish,
> Which are turbid because of ice
> And into which the snow melts. Job 6:15-16 NASB

Lack of vegetation and later post-Flood diversification of grasses

Early in the post-Flood times significant vegetation was probably sparse. Erosion rates would have been significantly higher considering the increased precipitation rates and the other factors that have already been mentioned. Today, grasses are a significant agent in holding soils in place and preventing erosion. Bloom (1998) suggests that the evolution of grasses had a significant geomorphic impact, not only for erosion rates on the continents, but depositional rates in the oceans (p. 51):

> The geomorphic impact of grass is hard to underestimate. Grasses are unique among plants in their ability to form a tight, shallow mesh of roots called sod or turf. No one doubts the ability of sod to prevent gully erosion, so it is likely that major changes in mass-wasting and overland runoff attended upon the evolution of grass. Related geomorphic effects such as delta growth and submarine sedimentation can easily be inferred.

Thus, there was probably a "badlands" landscape in most areas following the Flood until grasses were able to widely diversify. This would be true whether the post-Flood boundary is at the end of the Mesozoic or the Tertiary. Assuming the Cenozoic represents post-Flood rock, the earliest post-Flood fossil record of grass pollen is in the Paleocene and widespread diversification of grasses did not occur until the mid-Miocene (Kellogg, 2001). We are still not certain how to calibrate post-Flood time within the geologic time scale, but this could conceivably represent an interval from decades to centuries until there was significant grass cover following the Flood. Following the Ice Age, landscapes would have been barren as well. As glaciers melted (probably quickly) newly exposed areas had the potential to be quickly eroded due to no vegetation, unconsolidated till, and the large volume of water produced by the melting ice.

Importance of joints and faults

Joints (breaks and cracks in rock without significant movement) can frequently be found in all rock types (igneous, metamorphic and sedimentary). It is rare that an outcrop can be examined where joints are not present. Rock is brittle and has very little tensile strength. When it is torqued, it breaks easily. Joints can form as the result of regional flexure, pressure release, contraction due to cooling and tectonic stresses (Bloom, 1998). As continents lifted out of the oceans the brittle basement rock and consolidated Flood rock would have been broken. Joints often exhibit regional patterns and occur in "sets." They are important because these are areas of weakness in rock in which all types of weathering can begin. Joints provide avenues for groundwater movement, planes of slippage for mass movements, tectonic movement and stream course development and control. Deep joints can often be found along canyon walls which may help significantly widen and deepen existing canyons.

The "straightness" of many streams has been attributed to joints and faults, which mean these features, were in place before significant erosion occurred. Bright Angel Canyon, a side canyon of the Grand Canyon is a good example of a "straight" canyon due to the presence of a fault (Figure 4). Where joints and faults were present following the Flood, they would have formed natural river courses. In some cases these features might help explain how rivers cut through mountains and topographic highs, or have cut exceptionally deep canyons in short periods of time.

Meteor impacts

Based on currently available evidence, it appears meteor impacts are more widely represented in the Cenozoic record than any other part of the geological column (Snelling, 2012). We only have record of those that have fallen on modern continents and shelves; probably three times as many have fallen in the oceans. Whether hitting the land or the ocean, meteors can cause significant geomorphic change. Those falling into the ocean can create tsunamis which can impact coastal areas worldwide. Large meteors could potentially cause climate change (next section).

Climate change and effects

Climate change introduces new geomorphic elements which often lead to increased rates of denudation. Wet places that become deserts loose much of their vegetation and when they occasionally experience storms and flash floods it causes radical changes in geomorphology. An example would be the great changes that must have occurred as the Basin and Range area dried following the Pleistocene. Areas that become exceptionally wet, especially in tropical climates, experience very deep weathering and soil development as we see in parts of the Hawaiian Islands and in the South American rain forest. As continental glaciers withdrew (probably rapidly) they produced huge amounts of melt water within areas that were not covered with any kind of vegetation. Large discharge coupled with unlithified till should have led to massive downstream erosion and deposition.

It is likely mountain uplift caused radical swings in climate following the Flood (assuming mountain uplift continued into post-Flood times). As mountains were lifted high enough, they likely interfered with weather patterns and the jet stream which could cause global climate change. The Himalayas and the Andes should be considered as culprits if they arose differentially following the Flood.

There are a few places in Job where post-Flood climate change may be described:

> He withholds the waters, they dry up;
> He sends them out, they overwhelm the earth. Job 12: 15 NKJV
>
> From whose womb comes the ice?
> And the frost of heaven, who gives it birth?
> The waters harden like stone,
> And the surface of the deep is frozen. Job 38:29-30 NKJV

Plate tectonic movement and the recent rise of mountains

If the Cenozoic is mostly post-Flood, there has been a significant amount of plate tectonic movement in post-Flood times (a good bit of the ocean floor is Cenozoic; Austin, *et al*., 1994). It also appears that many mountains ranges had significant amounts of uplift late in the Cenozoic (Ollier and Pain, 2000), although many had significant amounts of uplift prior to this too (like the Rockies and the Appalachians). Both continental movement and mountain uplift have great geomorphic implications. Plate position affects ocean currents which in turn affects ocean temperatures, weather patterns and climate. Mountain uplift of course can lead to many avenues of denudation.

Isostatic Adjustment (Crustal Rebound)

Whenever large amounts of material are removed (melting of a glacier, massive amounts of erosion, large landslides, etc.) the ground below responds by rising upward. It rises more quickly at first and then slows with time. This process is called isostatic readjustment. If the ground was depressed by the addition of mass (as in the case of a thick glacier) the rising response after the glacier melts is sometimes known as crustal rebound. As brittle rock landscapes rise (after the removal of rock or ice) the rock will crack forming joints. In cases of rock removal along the course of the Colorado River, for example, rock has risen parallel to the river, making slight anticlines along the course of the river in some locations (Huntoon, 2003). Joints that form by such processes lead to weaknesses in the rock and more surface area being exposed, which in turn leads to further mass wasting (and deposition) potential. The more material that is removed, the more important this process becomes.

Isostatic consequences of melting glaciers have been well established. Rates of rebound can be astounding. For example, Ristaniemi *et al*. (1997) reported that part of the Finnish coast rose 100 m in less than 1,000 years due to melting ice and is still rising at the rate of 8 mm per year! Isostatic adjustment can also occur due to landslides. Smith and Wessel (2000) estimated that rebound rate of up to 109 m may have occurred on the island of Oahu due to the large Nuuanu slide. Depression of several meters would have also occurred on the seafloor under the debris field. It is worthy to note that these are probably relatively small landslides and isostatic changes, compared to those that may have happened immediately after the Flood.

The Hawaiian Islands and the potential of post-Flood chemical weathering

A good example of rapid post-Flood weathering can be found in the Hawaiian Islands. These islands are certainly post-Flood volcanoes in that they have no marine Flood sediments on their flanks. There is no evidence the islands were ever covered with water from Noah’s Flood. This means the erosion on these islands all had to be in a post-Flood setting after the islands had formed in post-Flood times. The northern islands have been more highly eroded than the southern ones-- where the current active volcanoes are located. The southern islands are almost in pristine condition compared to the northern islands (where volcanic activity is extinct) indicating the rapidity in which chemical weathering can occur. The erosion of the northern islands must have occurred in no more time than the 4,300 years since the end of the Flood. The islands demonstrate how quickly erosion can happen in hot, rainy environments primarily by chemical weathering. Hazlett and Hyndman (1996, p. 38) indicate that most of the Hawaiian streams are clear and therefore carry very little suspended sediment. Thus, the deep canyons present on the islands are probably not being primarily cut by abrasion, but by dissolution. A combination of warm temperatures, high precipitation rates and basalt containing large quantities of olivine and Ca-rich plagioclase (very unstable minerals when chemically weathered) contribute to rapid erosion of the landscape.

Biblical support for post-Flood catastrophism?

There is a passage in the ancient (post-Flood) book of Job that suggests catastrophism in terms of falling and crumbling mountains (those that were uplifted in Psalm 104:8) as and river torrents washing away the soil (Job is speaking):

> But as a mountain falls and crumbles away,
> And as a rock is moved from its place;
> As water wears away stones,
> And as torrents wash away the soil of the earth;
> So You destroy the hope of man. Job 14:18-19 NKJV

These are the kinds of processes that we would expect as the result of tectonically unstable sediments being uplifted at the Flood's end; and there appears to be some biblical support for it.

DISCUSSION

A Dynamic post-Flood world

The potential for all of these factors and processes, I believe, led to a very dynamic post-Flood world in regards to geomorphology. Certainly catastrophes have occurred in the recent past (Austin, 1984), but because of the factors mentioned above, landscape alterations would have been much greater in the years immediately following the Flood. These factors and processes should not be overlooked when considering the origin of modern day landscapes. I believe these processes significantly imprinted, removed, or in many cases buried the surface formed by retreating water at the end of the Flood. Thus, we need to be exceptionally careful when identifying geomorphic features caused by retreating Flood water. Geomorphology should only be a minor consideration (rank of 3, Whitmore and Garner, 2008) when identifying where the Flood/post-Flood boundary may lie. Geomorphology should not be used exclusively or primarily as a criterion for the Flood/post-Flood boundary as Oard has advocated in many of his publications. Instead, multiple criteria should be sought in placing the boundary, realizing that some things may be more important than others (Whitmore and Garner, 2008). Not only would large amounts of post-Flood erosion be expected, but thick deposits of the eroded material would follow.

Irrespective of where one places the post-Flood boundary, the rise of mountains *above* sea level (Ps. 104:8) would have had significant effects on whatever surface had been shaped by the Flood waters just prior to uplift. Let's consider a hypothetical mountain range that is uplifted out of the Flood waters. As the mountains are exposed several factors are immediately present which can lead to massive denudation: high relief, steep slopes, water saturated rock, lack of vegetation, created basins filling with water and overtopping, seismic activity (from mountain uplift) initiating mass movements of all types, and further instability created by isostatic rebound resulting from the removed material. The ensuing mass wasting processes would certainly be "local" in occurrence, but it would be occurring *everywhere* mountains were being uplifted! Thus, especially in mountainous areas or in areas of high elevation that have not yet been carved into mountains (Ollier and Pain, 2000) we should expect to see evidence of incredible amounts of erosion (like the Grand Canyon). Erosion is identified by missing surface strata. Oard commonly uses examples like Devils Tower (eastern Wyoming on the edge of the Black Hills), Boars Tusk (southwestern Wyoming, between the Wind River and Uinta Mountains) and the area of the San Rafael Swell (southeastern edge of the Uinta Mountains and just west of the Wasatch Mountains, Utah) as examples of where incredible amounts of surface strata have been removed (2006a, 2009; Oard and Klevberg, 2008). Not surprisingly, all of these areas are high in elevation and are in areas where we might expect large amounts of erosion in post-Flood times.

When one considers all the processes outlined above, and considers that each of these processes was occurring with intensities very much higher than known anywhere in the present, and considers that these effects, though local, are occurring across the entire surface of a planet reeling from the Flood catastrophe, there should be little evidence left of the surface of the immediate post-Flood earth. In short these processes should have either taken off hundreds to thousands of meters of sediment from that surface or buried that surface with hundreds to thousands of meters of sediments. In most places the sediments and landforms would be expected to be destroyed completely (eroded away), and in most of the remaining cases that surface would expected to be buried beneath a considerable pile of sediment. Thus, a vast percentage of the continental rocks of the planet (on the order of hundreds to thousands of meters depth) should date from either substantially before or after the end of the Flood. Very few rocks can be expected to date close to the end of the Flood (either before or after). When Flood and post-Flood rocks occur together (on the continents), they should be separated by a significant unconformity in most cases.

Geomorphology and the post-Flood Boundary

Currently, Michael Oard is the main proponent arguing for a late post-Flood boundary at or near the end of the Tertiary (2010a, 2010b). His arguments are primarily geomorphological ones (2004b, 2006b, 2007, 2008, 2011; Oard and Klevberg, 2008) resorting to retreating Flood waters (while the continents were still submerged) to carve many features such as water gaps, planation surfaces and pediments that can readily be identified today. He envisions a “sheet flow phase” followed by a “channelized flow phase” during Walker’s “recessive stage” of Flood water retreat (2001a, 2001b; Walker, 1994). (Although Oard often refers back to Walker’s paper as the origin of the terms “sheet flow phase” and “channelized flow phase” (e.g. 2012, p. 245) these words and concepts do not appear in Walker’s 1994 manuscript. The usage of these terms appear to have been first used by Oard (2001a, 2001b) as what might hypothetically happen when Flood waters retreated. No experimental or observational citations were made by him in those papers that documented that sheet flow leads to channelized flow; it was simply assumed.) It is my belief that Oard has correctly observed that erosion has been involved make these features (planation surfaces, etc.), but he has not adequately demonstrated that erosion from retreating Flood water caused these features in lieu of other post-Flood processes. In a section titled "Very Little Post-Flood Catastrophism" Oard (2001b, p. 91) states:

> A third implication [of a Late Cenozoic post/Flood boundary] is that there was little "post-Flood catastrophism" relative to some of the other models. Simply, the above model [vertical tectonics] would account for practically all major geological events that have been postulated as "post-Flood catastrophism" as occurring *during* the Flood. All major vertical tectonics and volcanism would have ended. Local "catastrophes" could have occurred after the Flood, such as the ice age, smaller-scale volcanism, local tectonics, landslides, and events such as the Lake Missoula flood… Those who advocate Cenozoic post-Flood catastrophism have published few reasons for their beliefs and have not addressed the criticisms of their ideas.

In the plethora of articles that Oard has written on geomorphology, he always assumes that very little catastrophism has happened after the Flood waters retreated. Oard believes that massive amounts of erosion happened underwater during mountain uplift (e.g. 2012) with only "local" erosion (and presumably not much deposition) happening after the mountains emerged above the Flood waters. A major thesis of this paper is that this initial post-Flood surface has been greatly modified or obscured by massive erosion and deposition in the centuries following the Flood. For example, in the Green River Basins of Wyoming, the Flood/post-Flood boundary is found deeply buried below lake sediments (Whitmore and Garner, 2008). Eroded sediments also need to be deposited somewhere. As mountains get vertically uplifted (uplift would continue to happen after the mountains were well above sea-level in my thinking), basins would form in between the mountains. These basins would quickly fill with sediments as a result of mass wasting processes from the uplifted mountains. Where basins are not present, sediment would be carried down drainages (via mass wasting processes) and form the vast sheets of deposits. Examples could include the apron of Cenozoic sediments that flank the Rocky Mountains or the sediments of the Mississippi River Embayment, which extend from the Gulf of Mexico to southern Illinois.

Because of expected post-Flood erosion that would occur, irrespective of where one places the post-Flood boundary, enormous quantities of sediment should be found resting on the post-Flood unconformity. An example might be the Salton Trough which has about 10,000 meters of Cenozoic sediments in it (Hussein *et al.*, 2011). In places that are higher in elevation (where no basin occurs for the collection of sediment) we might expect significant amounts of the original Flood strata to be missing (such as on the Colorado Plateau). Oard's high placement of the Flood boundary (at the end of the Tertiary) essentially ignores the expected quantity of sediment that must have been produced during this time. In Oard's model, retreating Flood water causes multiple features such as planation surfaces, water gaps and pediments; which are widespread in places like the western United States. However, these are surficial features that are *not buried*. If such features were produced by retreating Flood water, they should be either buried deep in basins or, if exposed, have been removed by post-Flood mass wasting according to the arguments presented here. Oard's high placement of the post-Flood boundary utterly fails because it does not take into account the massive amount of erosion and deposition that would have happened *following* the draining of the Flood waters.

The San Rafael Swell and the Colorado Plateau

A specific criticism that Oard and Klevberg (2008) and Oard (2008, 2010a) have used against my assertions (i.e., Whitmore, 2006 a-c) that the Green River Formation is a post-Flood deposit, is that there is too much erosion (4-5 km) in the area of the San Rafael Swell (central Utah) to be explained by post-Flood processes (Figure 5). The arguments presented here should make it clear this is not problematic, but expected.

Oard and Klevberg estimate 4-5 km of material has been removed from the San Rafael Swell; which might be a slight over estimate. The San Rafael Swell was a positive topographic feature well before any Green River Formation sediments were deposited. The concencous is the feature was in place during the Late Createous, although it may have continued to rise slightly since then (Christensen and Fischer, 2000; McGuire, 1998; Stokes, 1986; Weiss, Witkind, and Cashion, 1990). Oard and Klevberg stated the structure formed after the deposition of the Green River Formation (p. 103) without citing any literature or evidence supporting their new assertion. Sedimentary packages thin as they approach the structural high (Weiss, *et al*., 1990) in this area, indicating the structure was already in place, perhaps even creating the basin in which the sediments accumulated. Hintze (1988, p. 64) shows how the Green River Formation sediments accumulated *around* the San Rafael Swell, not on top of it. Considering this oversight, the estimated amount of material eroded has probably been slightly exaggerated.

Significant amounts of erosion have occurred in the area of the San Rafael Swell in particular and on the Colorado Plateau in general. Based on various processes, presented earlier, there are good reasons for this. A major physiographic and structural feature in the state of Utah is the Wasatch Line. It is a broad arc-shaped feature that runs north-south through the entire state. It separates the relatively stable Colorado Plateau (characterized by flat lying rocks that are actively being eroded that have been lifted high above sea level) from the more active Basin and Range Province (characterized by complex folding and faulting with deposition in basins, some of which are below sea level). The Wasatch Line cuts through the northwestern corner of Figure 6. Based on the arguments presented in the first part of this paper, the following factors would have been available to cause post-Flood erosion, well after this area had been exposed above sea level: 1) Mountain building activity along the Wasatch Line continued well after the Laramide Orogeny (K-T) and just after the Green River Formation (Eocene) was deposited (Stokes, 1986).

This led to great relief (to the west of the area) with drainages coming from topographic highs, crossing over the San Rafael Swell. Note the streams transversing the Swell in Figure 6. 2) Earthquake activity along the Wasatch Line was certainly great in the past and continues into the present time (Stokes, 1986). The Wasatch Fault is about 330 km long with a vertical displacement of almost 5 km. Large magnitude earthquakes would have occurred as the Wasatch mountains rose, accompanied by extensive mass wasting. 3) Both extrusive and intrusive igneous activty occurred along the Wasatch line well after the GRF was deposited (Oligocene and Miocene, (Stokes, 1986)). These three specific factors along with the more general factors mentioned earlier in this paper should have been significant enough in post-Flood times to cause the observed erosion, not only in the San Rafael Swell area, but over the entire Colorado Plateau. As we have seen, factors like mountain building, earthquakes and igneous activity set the stage for all types of mass wasting. With additional factors like high post-Flood precipitation (Basin and Range lakes to the west were filling with water at the time of the San Rafael Swell erosion), glaciation in the Uinta and Wasatch Ranges, rivers out of equilibrium from mountain building and possibly other factors-- conditions would have been ripe for massive denudation.

An additional factor that would certainly apply to the Colorado Plateau as a whole is isostatic readjustment. Some of the Green River Basins rest on the Colorado Plateau and others are north of it (Oard and Whitmore, 2006). Based on the fauna and flora found in these basins (Grande, 1984; Whitmore and Wise, 2008) they were not deposited at their current elevations, but much lower. Most of these relatively flat lying sediments are now more than 2,000 m above sea level! It is likely the basins were made somewhere near 300 m above sea level (or less) and then have risen (in late post-Flood times) to their current elevations. Stokes (1986, p. 150) uses the term “epeirogeny” which refers to broad regional uplift rather than localized mountain building which is appropriate for this area.

The evidence that the Colorado Plateau was exposed in the Cenozoic is compelling. Many marine formations are widespread over the entire western United States before the K-T boundary and then marine sediments suddenly disappear with the start of the Cenozoic (Figure 7). Not only do marine sediments cease, they are folded and faulted in the mountian uplifts that make up the Western United States. These marine deposits are covered by relatively flat-lying, undeformed, widespread terrestrial deposits that fill basins and outcrop over much smaller areas such as the Green River Formation (Whitmore and Garner, 2008). Whatever caused the continued uplift of the Colorado Plateau, it is clear that it happened. If the Green River lakes were deposited at lower elevations in the immediate post-Flood times, it means that the entire Colorado Plateau has been rising since the end of the Flood. Isostatic rise has probably been one of the leading post-Flood factors that has modified the Plateau since the end of the Flood. This needs to be considered in Grand Canyon erosion models, but has thus far been ignored by creationists working in this field. Isostatic rise in post-Flood times might be able to easily explain many anomalous river courses simply as superposed and antecedent streams.

CONCLUSION

As continents and mountains rose out of the Flood waters and were exposed as dry land, a number of denudation factors would have been immediately present including water saturated sediments, high precipitation rates, large storms, earthquakes, volcanic activity, rivers out of equilibrium, lack of vegetation, weaknesses in rocks (joints and faults), meteor impacts, isostatic rebound, plate tectonic movement, climate change and Ice Age floods. These processes would have been expected to occur with rates and magnitudes that are rarely, if ever, experienced today. Many of these processes would have been "local," but their widespread and cumulative nature would have radically changed landscapes *everywhere*. Because of these processes, the immediate post-Flood landscape would have been rapidly eroded and likely had the appearance of "badlands" before trees and grasses could become re-established. In all likelihood, these processes would have totally removed any planation surfaces, water gaps, pediments and other such features that have been imagined forming just before the continents were lifted out of the oceans at the Flood's end. In my opinion, it is unthinkable that these kinds of features would have survived the post-Flood world unless they were immediately buried. Additionally, these processes would have led to depositional rates that are much higher than rates that we observe today. This has implications for the filling of inland basins, the size of river deltas and the thickness of post-Flood ocean floor sediments. These considerations need to be worked into Creationist views of earth history. The Flood/post-Flood boundary is either buried or deeply eroded in most cases. It should *not* be a feature that is readily apparent and relatively unmodified.

Based upon the likelihood of massive post-Flood denudation, alternate hypotheses (other than Flood water retreat) should be sought in the formation of planation surfaces, pediments, water gaps, rivers cutting through mountains, and the erosion of the Grand Canyon. Although it is beyond the scope of this paper to discuss how such things as pediments might form as a result of these processes, it should be noted that mass wasting deposits can sometimes be mistaken for pediments (Williams, 1984). Creation geologists have the potential to make real progress in geomorphology when correctly understanding the placement of the post-Flood boundary, the vulnerable nature of freshly uplifted Flood rock and the great potential for post-Flood mass wasting. As Creation geologists we need to begin thinking seriously about *post-Flood catastrophic geomorphology* in shaping every landscape in our present world.

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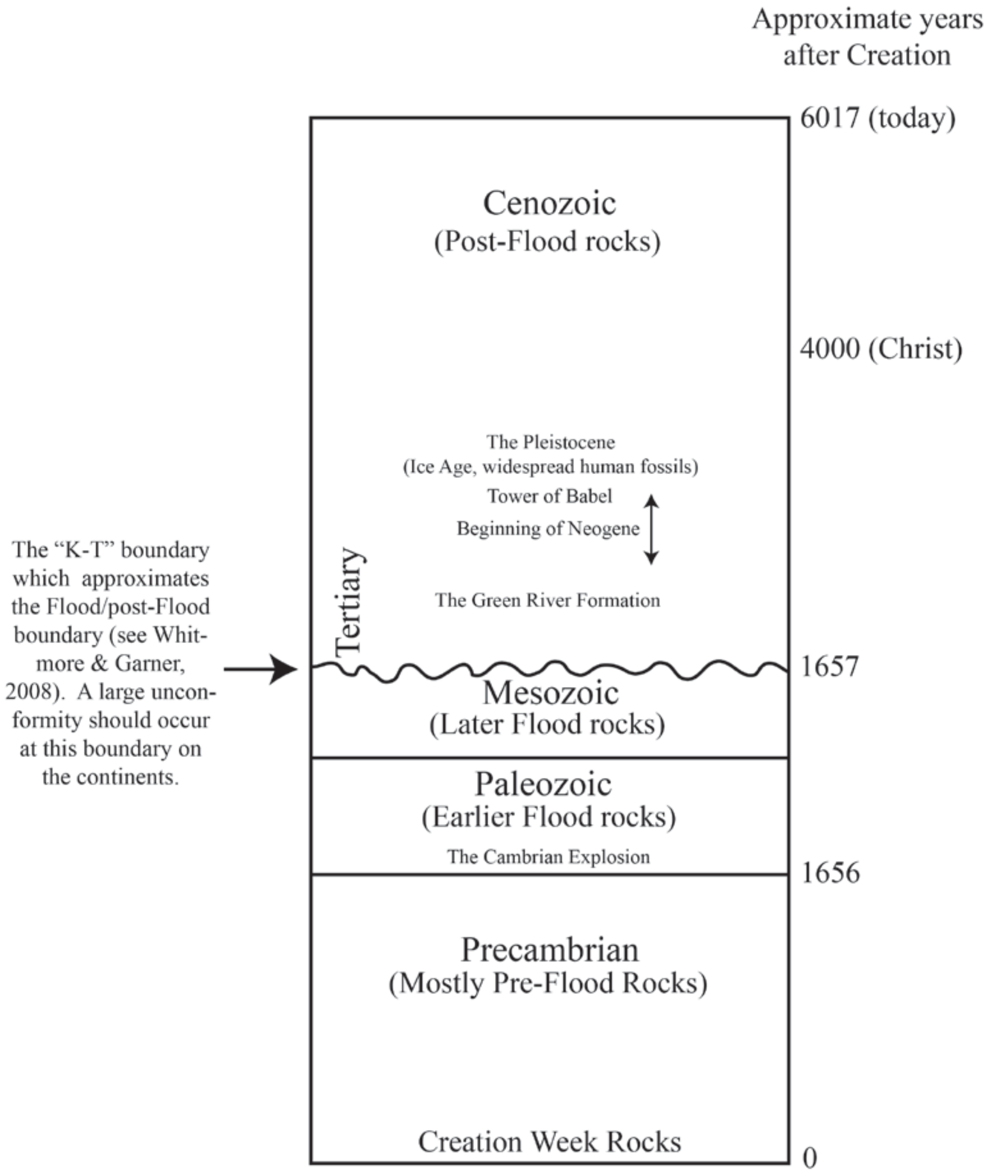

Figure 1. A geological column from a biblical perspective with selected events (not drawn to scale). Note that the Flood only represents one year of time, although it often accounts for a relatively thick sequence of sedimentary rocks. The pre-Flood time and the post-Flood time would have been the longest periods in earth history accounting for approximately 1,656 and 4,362 years, respectively. The terms "Precambrian," "Paleozoic," "Mesozoic" and "Cenozoic" are defined by the fossils they contain, not their conventional radioactive ages. This paper argues that tremendous post-Flood erosion would have produced a widespread unconformity (in most continental areas) at the "K-T" boundary and thick post-Flood deposits resting on the unconformity. Drawing by John Whitmore.

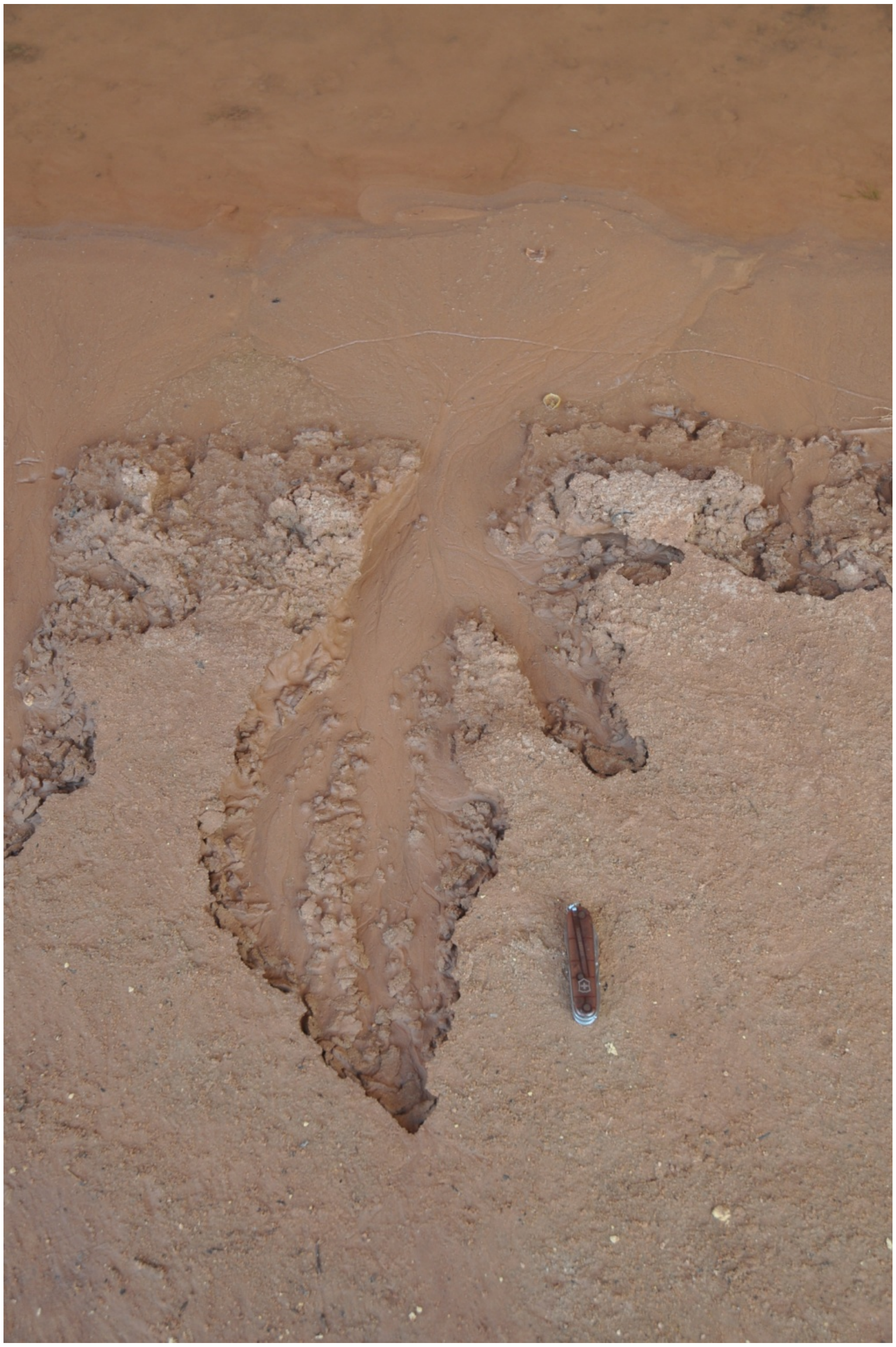

Figure 2. Groundwater sapping easily occurs as water runs down-dip through sediments forming amphitheater-like canyon heads. The photo is taken from above and water is running from the bottom of the photo to the top. Pocketknife is 9 cm in length. The “cliffs” are about 5 cm high. Notice the triangular delta of material that has been carried to the river by mass flow processes. The “plateau” where the knife rests still remains relatively flat and unaltered. Photo by John Whitmore.

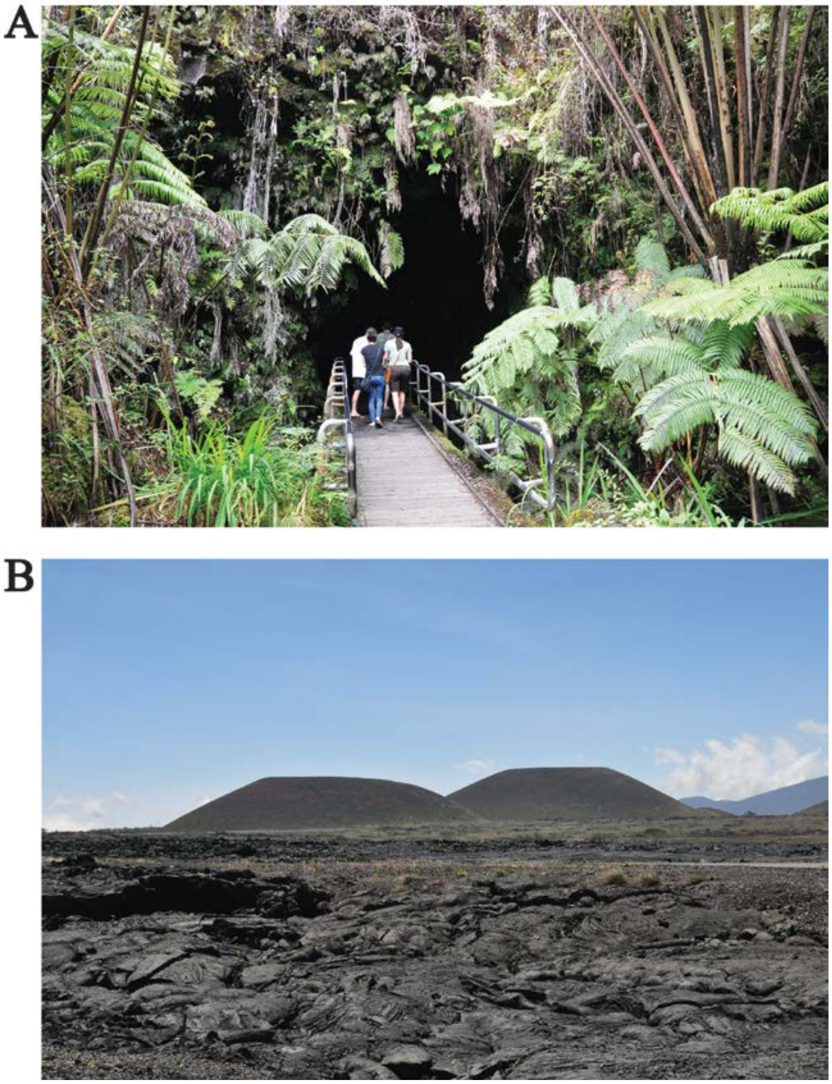

Figure 3. A pair of photos to illustrate how fast weathering and soil development can happen based on precipitation rates. Both pictures are from the Big Island of Hawaii. The first picture (A) is taken at the entrance to the Thurston Lava Tube, an area of very recent volcanic activity. Note the jungle surrounding the entrance. Even though there are recent lava flows in the area, high precipitation rates cause rapid weathering and thick soil development in this area of the island. The second picture (B) is from the “saddle” between Mauna Loa and Mauna Kea, an area of lava flows dating from about 1855 to 1935 and cinder cone activity during the centuries before that. Lower precipitation rates on this part of the island cause the volcanic rocks to weather more slowly, and little soil is produced. Here the flows remain “fresh” for centuries because of the lack of precipitation. Photos by John Whitmore.

Figure 4. The Colorado River, which runs through the Grand Canyon, is hidden in the deep canyon running left to right in the photo. Looking to the north, Bright Angel Canyon can be seen as a long straight Canyon extending off into the distance. It follows the trace of the Bright Angel Fault. Its straightness is attributed to the presence of the fault. Photo by John Whitmore.

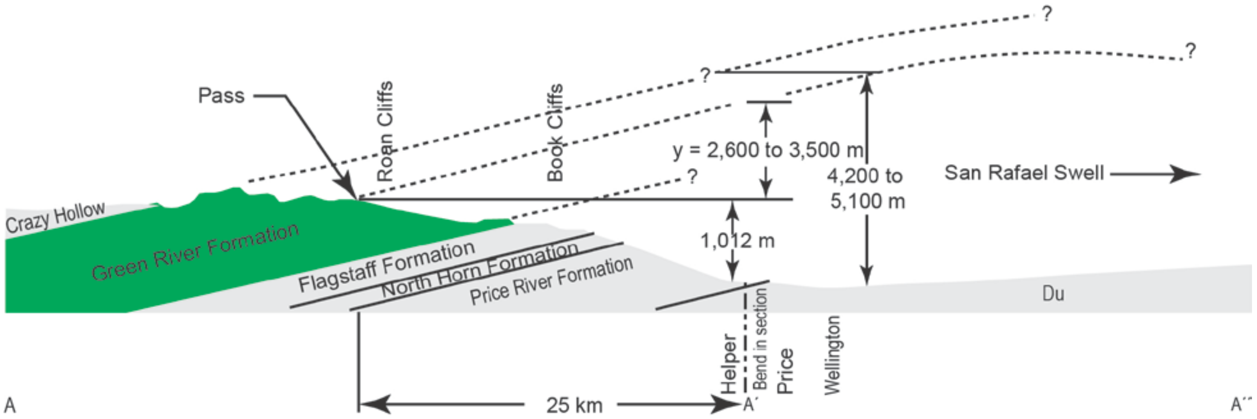

Figure 5. Figure used by Oard (first appearing in Oard and Klevberg (2008) and used several times later) arguing the Green River Formation of Colorado, Utah and Wyoming must have been deposited by the Flood. His argument is that there is simply too much Green River Formation that has been deposited and eroded away to be explained by post-Flood processes; therefore it all must have been done during the Flood. This paper argues post-Flood processes were more than adequate to explain both tremendous deposition and erosion in post-Flood times.

Figure 6. Google Earth view of the north end of the San Rafael Swell, near Green River, Utah. Interstate Highway 70 runs east and west near the bottom of the figure (the orange road). The San Rafael Swell is a large doubly plunging anticline about 130 km long and 60 km wide. The distance between Green River and Huntignton is about 80 km. North is toward the top of the photo. A tremendous amount of material has been removed from the top of the anticline, estimated by Oard and Klevberg (2008) to be 4-5 km. Photo downloaded on August 6, 2012.

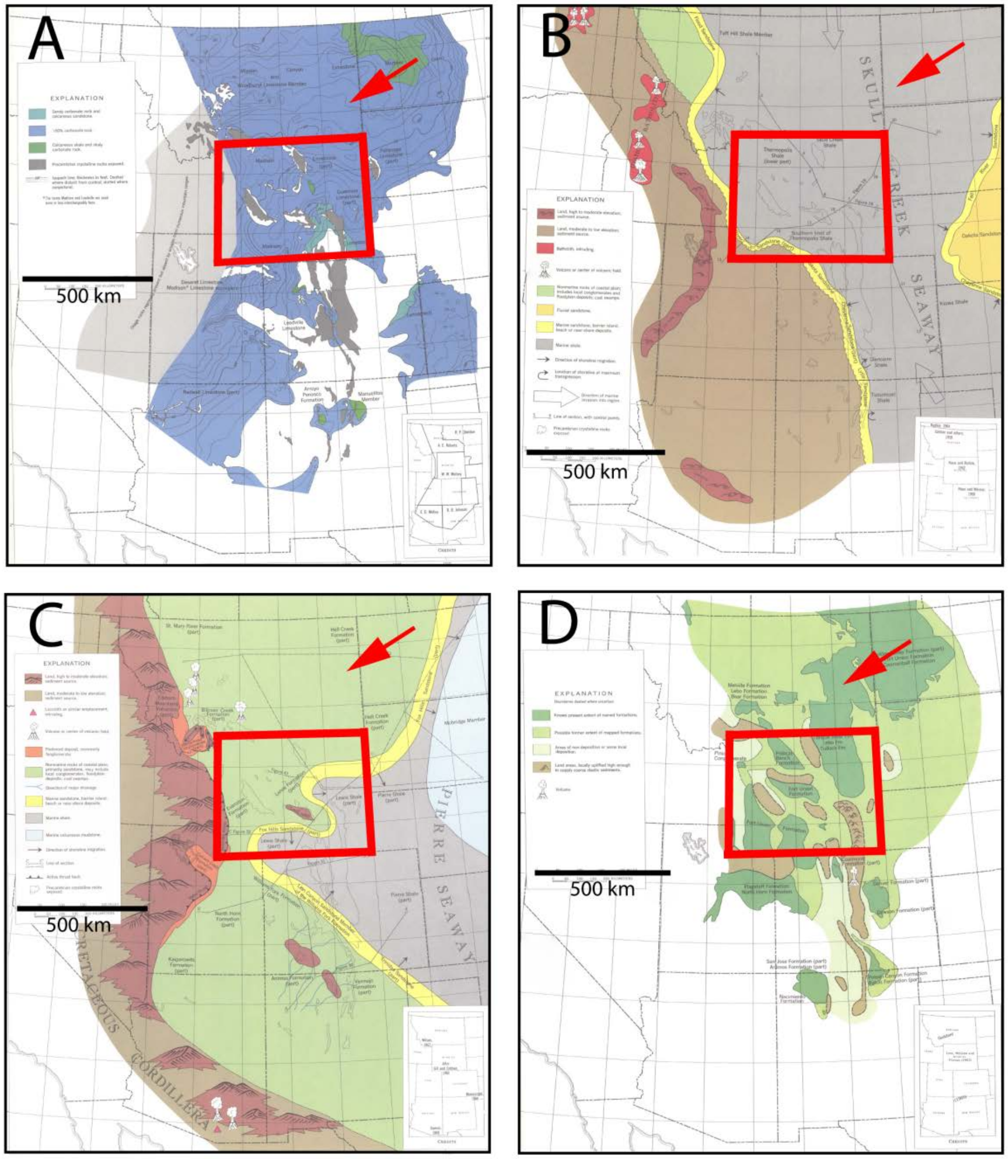

Figure 7. Maps showing changes that take place in aerial depositional extent of formations during A-deposition of the Madison Formation (Paleozoic), B-deposition of the Thermopolis Shale (Mesozoic), C-deposition of the Lance Formation (Mesozoic), and D deposition of the Fort Union Formation (Cenozoic). Formations indicated by red arrows. The state of Wyoming is highlighted in red. Note the aerial extent of deposition changes rapidly from C to D. This is also a change from dominantly marine to dominantly non-marine that occurs at the K-T boundary. Figures modified from the *Geologic Atlas of the Rocky Mountain Region*: A—Craig (1972, p. 105); B—McGookey (1972, p. 200), C-- McGookey (1972, p. 225); D—Robinson (1972, p. 237). Previously published as Figure 3 in Whitmore and Garner (2008).

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