The geologic setting of the Green River Formation

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Further evidence is presented that the Green River Formation (GRF) was deposited after the Flood following the tectonic uplift of Psalm 104:8. A shift from continental-wide to regional sedimentation patterns within local basins makes this clear. Additional evidence suggests the GRF was deposited in a warm lacustrine ecosystem over a period of hundreds of years, suggesting the need to re-evaluate post-Flood climate models. Sedimentological, stratigraphic and structural evidence suggest pediments, developed on GRF basin fills, could not have formed until well after the Flood. For now, creationists should abandon the use of paleontological criteria (index fossils) in defining the post-Flood boundary and focus on sedimentological and stratigraphic criteria instead.

Introduction

This article is primarily a response to Oard's[1] first submission of this forum. It is impossible to respond to every point in his original article because of the focus of this forum and space limitations. I will respond to what I believe are his most serious objections to the Green River Formation (GRF) being post-Flood. Additional evidences will be presented that the GRF and its associated basin fills are post-Flood. Several solutions are suggested for the apparent contradiction between the warm post-Flood environment indicated by the GRF and the cool post-Flood climate model developed by Oard. In this paper, I develop criteria which can be used to define the post-Flood boundary independently of index fossils. This approach may be a significant step forward in understanding the 'geologic column' and its associated fossils in other areas of the world, and may help to resolve some of the controversy related to the post-Flood boundary.

Shift in sedimentation patterns

In examining the geologic column of west-central North America, we note a tremendous shift in stratigraphic sedimentation patterns from the Mesozoic to the Cenozoic. Mesozoic sections are dominated by marine deposits which are continent-wide and laterally continuous, compared to the lesser-scale, stratigraphically-isolated, regional deposits of the Cenozoic[2] (like the GRF). These Mesozoic deposits *stratigraphically and unconformably underlie the GRF*.[3–8] I believe the best explanation for this shift in sedimentation scale (from continental-wide to regional) is the end of the global Flood catastrophe. The unconformity found below the Green River Basins (typically below the basal member of the Wasatch) likely represents Flood water flowing off the continents as the surrounding mountains were uplifted and the basins were formed (Psalm 104:8). The Green River basins, and likely many of the other basins throughout west-central North America (figure 9*), are best explained as basins that developed and started to fill as a result of the processes in Psalm 104:8. The shift from continent-wide to regional sedimentation patterns indicates we are clearly past Genesis 7:20, the point at which the floodwaters reached their maximum height. The complete absence of marine fossils in the basins also suggests the Flood had retreated by the end of the Mesozoic in this area.[2]

Rapid accumulation of basin fills

It has been demonstrated that the 'varves' of the GRF (evidence often cited for millions of years of sedimentary activity) cannot be annual.[9,10] As argued in my first submission,[11] fish taphonomy, multiple layers of stromatolites and caddisfly mounds argue that the sediments must have taken more than weeks to be deposited. Evidence for longer periods of time also occurs stratigraphically higher, in the Bridger Formation, where turtle preservation patterns argue for time much longer than weeks.[12] Each turtle mass mortality layer (at least four are reported) indicates that weeks (probably months) passed to explain the taphonomic absence of turtle heads and limbs, but the presence of articulated shells. Whereas articulated turtle shells indicate they were not exposed for long periods of time (years) before burial.

There are no scriptural mandates against post-Flood catastrophism. Indeed, we still have geologic catastrophes in today's world (consider the 2004 Indian Ocean tsunami or the Missoula flood[13]). Fossil fish,[14] coprolites,[15] large ball and pillow structures[5] (figure 31), intrastratal hydroplastic flow[16] (figure 32) and convoluted beds[17,18] all argue for rapid accumulation and subsequent lithification of thick sedimentary layers within the GRF. I suspect it took less than a few hundred years for the Green River Basins to fill. In the future, creationists should look for vertical patterns in the GRF (such as fish taphonomy,[14] fish scale patterns,[19,20] pollen and leaves) which might indicate seasonal changes that can in turn be interpreted as yearly deposits. This would

* Figures are numbered continuously through all the articles in this forum.

Figure 31. Large 'ball and pillow' structures in the Laney Member of the Green River Formation along Interstate 80, Green River, Wyoming. Note the semi-truck for scale in the bottom left of the photo. The structures were formed as the Sand Butte Bed (near the top) transgressed over the carbonates of the LaClede Bed (near the middle). The soft carbonates of the LaClede Bed could not support the sudden accumulation of the Sand Butte Bed, resulting in hydroplastic failure of the section, forming the ball and pillow structures. They are commonly recognized to form in this fashion.[63] The outcrop shows that the carbonate muds were not yet lithified when the sand was catastrophically dumped on top of them; an unlikely scenario if millions of years are represented by the Laney Member.

help us calculate how much time the sediments of the GRF actually represent.

The margins of the Green River basins consist of *clastic* sediments and sedimentary structures consistent with deltaic, fluvial and alluvial settings.[11] The sediments include thick accumulations of sandstones and conglomerates which interfinger with fine-grained lacustrine sediments.[7] For example, in the northern Green River Basin, the GRF laterally interfingers with the Wasatch, which in turn grades into the Pass Peak Formation, an alluvial conglomerate possibly up to 975 m thick![21] As the basins filled, clastic sediments (represented by the Bridger and Wasatch Formations) eventually transgressed over the lacustrine deposits below.

The bulk of the Green River basins are filled with *carbonate* sediments, mostly in the form of calcimicrite. Lake carbonates have several sources including: inorganic, photosynthetic induced, biogenic and detrital.[22,23] Biogenic microbial carbonates are poorly understood[24–26] and may be an underappreciated source for many of the GRF carbonates. Large algal blooms, coupled with warm water, can decrease the amount of CO_2 in lakes leading to supersaturation and precipitation of calcite.[23] If post-Flood CO_2 concentrations were high, they may have contributed to large algal blooms. Increased post-Flood CO_2 levels could have resulted from massive biological decay and volcanic activity. These types of processes may explain both the rich accumulation of organics and carbonates in the GRF. Models arguing the Green River sediments were catastrophically deposited as turbidites or some other mass flow process[15] are easily rejected based on sedimentological and paleontological criteria.[14] Buchheim and Eugster[27] developed a model explaining the origin of laminated calcite/organic rich couplets within Fossil Basin (figure 33). Independent methods of determining accumulation rates (discussed above) will have to be used to determine if this model can explain the basin filling in a short period of time.

Rapid erosion of filled basins

As I suggested in my first submission,[11] rivers could not begin to erode the sediments of the basins, until the basins had been completely filled. After filling, regional rivers could transverse former drainage divides, and exhumation could begin. This sequence of events is supported by sedimentology. The GRF is stratigraphically followed by the deposits of the Bullpen member of the Wasatch Formation and the Bridger Formations. Occasional shallow lakes still persisted during this time.[12,28] It is likely the rivers, which deposited fluvial material on top of the GRF, eventually were able to cut down through it. Sedimentology of the Bridger Formation indicates the area was still tectonically and volcanically active,[28] likely leading to increased erosion rates. Increased erosion rates have been noted in such regimes today.[29] Geomorphic changes in unconsolidated sediments can proceed rapidly until dynamic equilibrium is reached within the landscape.[30] It is likely the Bridger and Wasatch were unstable because multiple landslide deposits of these formations are common.[31] Creationists have noted many other examples of modern rapid erosion rates and canyon formation.[13,32,33]

Where have all the eroded sediments of the GRF gone? They have been transported downstream into the Colorado River drainage basin. The eroded sediments of the Green and Colorado drainage basins can now be found in the extensive Colorado River delta deposits of the Imperial and

Diablo Formations along the California/Mexico border.[34,35]

The climate of the Green River Formation

Climate inferences for the GRF are based on multiple lines of evidence from paleontology and sedimentology.[5,36–39] Fossil pollen and fish indicate a relatively warm environment, perhaps with cool winters. Isotopic evidence suggests significant winter snowfall was present in the Uinta Mountains during deposition of the GRF.[40] This helps explain the paradox of mixed subtropical and cool elements that Oard suggested was a signature of Flood deposition.[1] The large accumulation of carbonate sediments, strongly argues for a warm climate, as calcium carbonate readily dissolves in cold water.[23] Because nearly complete ecosystems are represented[37,41] and taphonomy doesn't indicate transport[14] it appears the fossils are valid climatic indicators.

In contrast, Oard's post-Flood glaciation model suggests cool climates and glacial development immediately followed the Flood.[42] Since the Green River Basins are deep in the continental interior, at about 40° N in latitude, and currently at relatively high elevations (>2,000 m), post-Flood climate models don't agree with the climate actually indicated by the fossils and sedimentology. These ideas need to be tested, but here are several solutions, which may partially explain the enigma:

Figure 32. Intrastratal hydroplastic flow in the Laney Member of the Green River Formation, just above the Orange Marker Bed. The location is near Chicken Springs Draw, Flaming Gorge, Wyoming. The 'blebby' nature of this bed may have been the result of liquefaction during tectonic activity. During shaking, the middle layer became temporarily 'liquid' and clasts of the upper, darker layer sank into the middle layer. Regardless of how the intraformational deformation occurred, the outcrop shows the carbonate muds were not yet lithified when deformation took place, indicating a short time lapse between deposition and deformation. Intrastratal hydroplastic flow is also indicated by contorted beds along this same horizon. The U.S. penny is 1.9 cm in diameter.

1. Perhaps post-Flood climate models are wrong. Dramatic cooling and glacial development may not have occurred until several hundred years after the Flood. The rocks of the Green River Basins are partially covered by glacial moraines sourced from the higher, Uinta Mountains.[31] So glaciation did develop, but not until the Green River Basins had been well established and mostly filled.
2. Perhaps the entire region was vertically uplifted, a second time (the first was Psalm 104:8) after the deposition of the Green River Basin fill. While at lower elevation, warmer climates could be sustained. Renewed uplift might also help explain the massive exhumation that has occurred throughout much of the Green River Basins.
3. Too much post-Flood volcanic activity presents a problem for a relatively warm climate as massive volcanic activity would produce too much worldwide cooling.[43] Perhaps there were some other atmospheric factors that contributed to an extended, warm, post-Flood, continental climate, despite volcanic activity. Could the heat produced from cooling igneous plutons (to the west) or extremely warm oceans have been enough to offset the cooling effects of volcanic gases? Could excessive amounts of CO_2 (produced by biomass decay and volcanic activity), have offset the effect of volcanic aerosol cooling? CO_2 is a 'greenhouse' gas that traps infrared heat and prevents it from leaving the atmosphere. Factors like these may have offset the cooling effect of volcanic aerosols longer than predicted.[42]
4. Did hot springs and large post-Flood pluvial lakes[42,44,45] play a significant role in moderating the climate of the west-central United States? It is known that large bodies of water play significant roles in climate moderation. Sloan and Barron[46] found it was impossible to generate warm climates in the west-central United States during the Eocene with their initial climate model. However, four years later, when Sloan[47] considered the moderating effect that a large lake(s) could have on climate (the Green River lakes), he found the climate could be 'equable'. In my post-Flood model, the Green River lakes would be present at about the same time as all of the pluvial lakes (figure 34), to the west in California, Nevada and Utah. The moderating effect of these lakes may have been significant, especially if they developed immediately following the Flood as Oard[42] and others[44] have suggested.

There is evidence of springs within the sediments of the GRF.[48–50] If these springs were hot (as many springs in

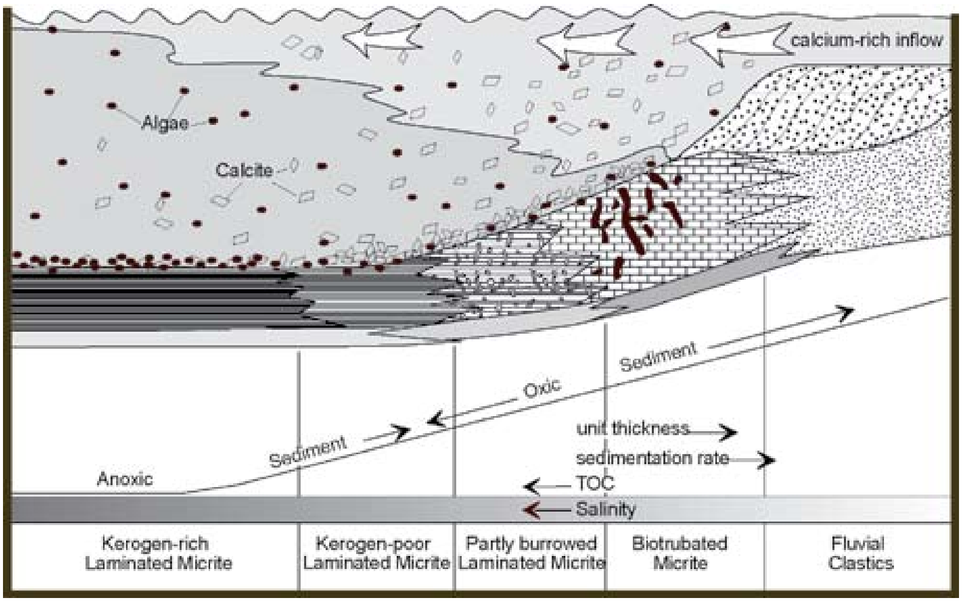

Figure 33. A depositional model for Fossil Basin developed by Buchheim and Eugster.[27] The model explains the lithology and distribution of laminated sediments in Fossil Lake.

Wyoming are today), perhaps they added to the moderating effect of these lakes.

Pediments and quartzites

As discussed earlier, the Cenozoic basins are regional deposits, only rarely connected stratigraphically with each other,[2,8,51] implying that they formed well after the final retreat of floodwaters that had covered the entire region. The basins formed (and filled) as a result of tectonically exposed highland areas all around them. Sedimentary current directions indicate radial fill patterns from the edges to the centres of the basins. In order for this to happen, the uplift of Psalm 104:8 must have already occurred and floodwaters must have already retreated. With this scenario, it is impossible for the pediments superimposed on the Green River basins to have formed as a result of retreating floodwater!

If I understand Oard's pediment model correctly,[52] he believes most pediments formed as a result of lateral erosion by retreating floodwater flowing around mountains and other highland areas at the end of the Flood (after the deposition of most of the Cenozoic). The problem with this mechanism, at least in the Green River basins, is that you can't have free flowing currents from one basin to another carving the pediments if the basins are *already* present. The basins are *enclosed* by mountain ranges and there is nowhere for the currents to go except toward basin centres! If it was possible for draining floodwater currents to flow from one basin to another, the basins should be widely connected stratigraphically; they are not. It is impossible to explain the GRF pediments by retreating floodwaters. In this case, the stratigraphy of the underlying rocks *do not* support that the pediments were cut as mountains were uplifted and floodwaters drained off the continents (Psalm 104:8). We need to look *below* the basins for the unconformity cut by retreating floodwaters, not on top of them. Indeed, the Green River and other equivalent basins are *underlain by a quartzite covered unconformity*,[8,53,54] which likely represents retreating floodwaters. Froede[55] seems to agree that the Late Cretaceous of the area (which underlies many of these basins) marks the beginning of Flood water retreat. The Green River pediments must have formed by some other, still unknown, mechanism.

It is unlikely that the quartzites we found covering some pediment-like surfaces in the GRF came from central Idaho during pediment formation. As argued above, the mountains had to exist in order for the basins to fill with sediment. The pediments (covered with quartzites) had to form *after* the basins were filled and started to erode. How can quartzites be transported over all the mountain ranges between Idaho and Wyoming? A much better source for the quartzites is the Uinta Mountains in the immediate proximity

Figure 34. Pluvial lakes in the western United States during the 'Ice Age'. Could these lakes have been contemporary with the Green River Formation lakes? (After Oard).[45]

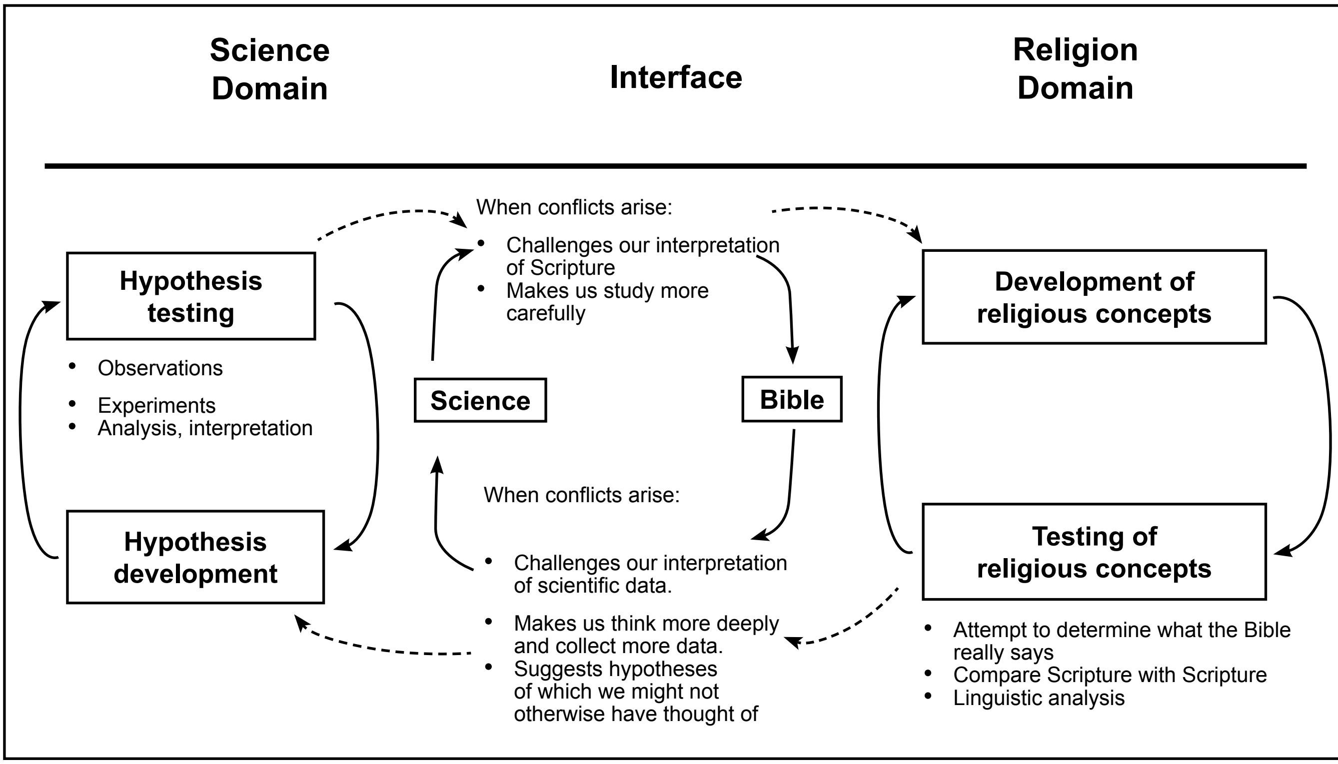

Figure 35. Brand's model[61] of a proper relationship between the 'domain of science' and the 'domain of religion' and how we should deal with conflicts when discrepancies arise between the domains. Brand has an excellent discussion of this process in his book.

to all of the Green River Basins[56,57] or from Precambrian and Paleozoic thrust sheets to the west.[56]

Defining the Flood/post-Flood boundary

Some work has been completed on how the Flood/post-Flood boundary should be defined.[52,58–60] However, this task has proved difficult. Before the boundary can properly be recognized and applied worldwide, we need to come to grips with how much post-Flood catastrophism, erosion and diversity within living things is possible. Brand[61] has proposed an excellent model (figure 35) for how we should approach these types of questions. This approach can be used to develop and test criteria used in defining the boundary. It can also be used to help us to decide the parameters of post-Flood catastrophism and the biological limits of diversity.

Holt,[59] Oard[58] and others have listed valid concerns for interpreting most of the Cenozoic as post-Flood. However, the mistake I believe they make is they are assuming the 'Eocene' in Wyoming was deposited at the same time as 'Eocene' everywhere else around the world. This is the same assumption made by conventional geology that makes biostratigraphy possible. What justification do we have as creationists to make such assumptions? Could it be that the Eocene in Wyoming was being deposited at the same time as parts of the Permian or Pleistocene in other parts of the world? To decide this, we need to develop other criteria for boundary determinations (besides using index fossils and absolute 'position' within the geologic column). The trap that many have fallen into is that they want to assign the post-Flood boundary to a 'spot' in the geologic timescale and then apply it worldwide. We must remember that divisions in the Phanerozoic timescale are based on index fossils, not sedimentology. As creationists we need to start using sedimentological and stratigraphic criteria (as I have done in this submission) to determine the location of the boundary. I think we should shy away from using the geologic column 'ages' to define boundaries within the Flood until we better understand the limits of biological speciation and what the sequence of fossils actually represents. The developing field of baraminology[62] shows great promise in this area.

I am not saying that paleontology and the order of fossils has no value. However, post-Flood paleontology may be more complicated than we think because of changing populations due to climate shifts. Until we have a better understanding, we should take a safer and much more reliable approach of using sedimentological and stratigraphic criteria in defining Flood boundaries. I commend Oard in starting to use geomorphology to help in the definition of the post-Flood boundary, but the sedimentological and stratigraphic evidence in the rocks below the landscape cannot be ignored.

Conclusion

The post-Flood setting of the GRF was a time, likely hundreds of years in duration, in which the earth was trying to reach a state of equilibrium following tremendous tectonic and climatic changes during the Flood. The sediments of the GRF record rapid depositional events accompanied by tectonic and volcanic activity in a relatively warm, lacustrine ecosystem.

The Green River lacustrine sediments (carbonates) interfinger with coarser fluvial and alluvial sediments (clastic) at their margins, as would be expected in such a tectonic setting. Green River basin fills are unconformably underlain by laterally continuous continental-wide marine deposits. This pattern is present because the tectonic uplift of Psalm 104:8 has already occurred, and floodwaters have retreated.

Logic dictates that the basins could not have been filled before they were formed. They formed by the uplift of the surrounding mountain ranges. It is clear the basins were tectonically isolated from one another making pediment formation on GRF deposits by draining floodwaters impossible. Instead, draining floodwaters formed the unconformity found *below* all the basins. Because glacial sediments stratigraphically overlie the GRF and because of warm climatic indicators, the timing and development of post-Flood glaciation models may need to be reconsidered. Special conditions such as warm, spring fed lakes, pluvial lakes, and cooling igneous plutons to the west may have contributed to moderating the climate of Wyoming after the Flood.

Creationists should abandon the use of paleontological criteria or 'geologic age' in defining the location of the post-Flood boundary (at least for now). Instead we should use sedimentological and stratigraphic criteria in determining the cessation of Flood processes. This approach may be a significant step forward in understanding the 'geologic column' and its associated fossils in other areas of the world and may help resolve some of the controversy related to the post-Flood boundary. Instead, paleontology should be used to test the development of post-Flood ecosystems and climates.

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