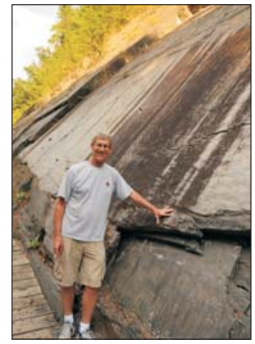
Article

Sediment Transport and the Coconino Sandstone: A Reality Check on Flood Geology



Timothy K. Helble

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The origin of a graphical procedure developed by a prominent Flood geologist to estimate the water depth and current speed associated with deposition of cross-bedded sandstones during a global Flood is examined. It is shown how this graphical procedure was used to estimate a widely quoted depth and speed of Flood waters said to be responsible for depositing the Coconino Sandstone and other Grand Canyon sandstones in a matter of days. Simple calculations are then performed to show that sediment transport rates much greater than anything reasonably associated with this estimated water depth and current speed would still be grossly insufficient to deposit the Coconino in a matter of days.

Flood geology—an effort by young earth creationists (YEC) to prove a global Flood was responsible for depositing all or most of Earth's fossil-bearing sedimentary rock layers—is rejected by mainstream geologists. Probably the best one-sentence summary of their objections to Flood geology was published by the National Academy of Sciences:

> The belief that Earth's sediments, with their fossils, were deposited in an orderly sequence in a year's time defies all geological observations and physical principles concerning sedimentation rates and possible quantities of suspended solid matter.[1]

Mainstream geologists validate this statement through their normal course of work and have provided innumerable independent lines of evidence indicating Earth's stratigraphic record was formed by complex processes over "deep time." In the past, mainstream geologists have generally not responded to Flood geology to avoid the appearance of granting legitimacy to young earth creationism. However, due to the impact that aggressive YEC ministries are having on the American public, mainstream geologists are beginning to realize a more organized response is needed.[2]

Several Christians have made concerted efforts to explain the errors of Flood geology and have alluded to the problem of sediment transport. Citing a graphical procedure presented by prominent Flood geologist Steve Austin in *Grand Canyon: Monument to Catastrophe* for estimating Flood current velocities said to be necessary to deposit cross-bedded sandstones,[3] Greg Neyman qualitatively explained how sediment transport in a year-long Flood would be insufficient to form a single, conspicuous sedimentary formation in Grand

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Canyon known as the Coconino Sandstone.[4] Also in reference to the Coconino Sandstone, Davis Young stated that "no flood of any size could have produced such deposits of sand."[5] Alan Hayward pointed out that the volume of Earth's Phanerozoic (542 million years ago to present) layers "alone comes to 654 million cubic kilometers, whereas the total amount of water on Earth is less than 1,400 million cubic kilometers." Thus, he argued, the Flood would be "a rich, creamy mud, in which no fish life could possibly survive."[6] The usual YEC response to such critiques is to state that they reflect "uniformitarian bias" or "the different starting point" of the "secular scientist" or "evolutionist."

Hill and Moshier recently described the basic tenets of Flood geology and provided several biblical arguments against it before presenting numerous evidences contradicting the young-earth view of Grand Canyon.[7] After a summary of geologic evidence against the young-earth view of Grand Canyon, this article uses a simple quantitative approach based on Neyman's explanation of the sediment transport problem to finalize its case against Flood geology. The "different starting point" response is circumvented by beginning with Austin's graphical procedure. It is then shown how Austin's own data, references, and arguments, when taken to their logical conclusion, refute the Flood geology interpretation of the Coconino Sandstone without any additional information or assumptions from "uniformitarian geology."

Grand Canyon Geology Review

The right side of figure 1 is a simplified stratigraphic section of Grand Canyon showing the position of each named formation. The following brief overview presents only a fraction of the independent lines of evidence pointing towards great age for the rocks of Grand Canyon. This overview draws heavily on geoscientists' papers in *Grand Canyon Geology*.

In *Grand Canyon: Monument to Catastrophe*, Austin classifies rocks from the Proterozoic eon (2.5 billion years to 542 million years old) as "pre-Flood/ Creation week," Paleozoic era (542 million years to 251 million years) as "early Flood," Mesozoic era (251 million years to 65.5 million years) as "late Flood," and Cenozoic era (65.5 million years to present) as "post Flood."[8] Austin uses the 150-day point mentioned in Gen. 7:24 and 8:3 to define the boundary between the early and late Flood periods.[9] This is essentially the same classification of layers as the

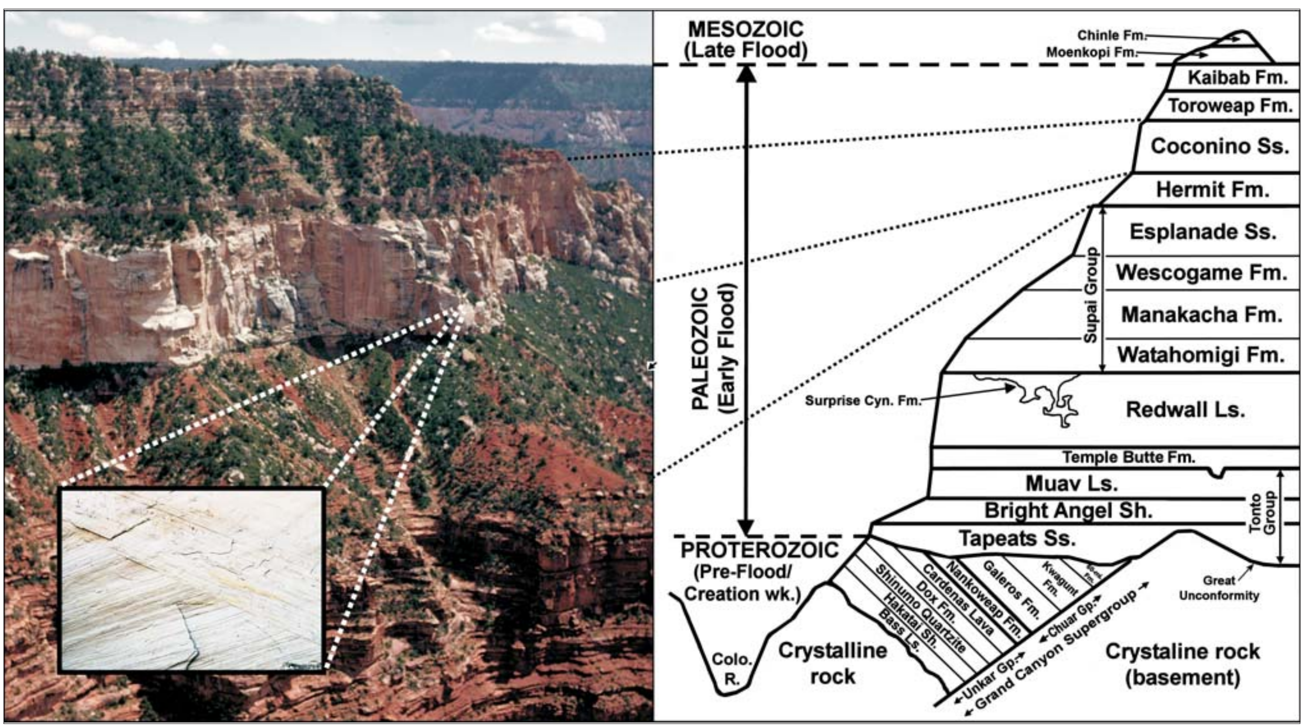

Figure 1. Photograph of Coconino Sandstone alongside simplified stratigraphic section of Grand Canyon, with inset showing the cross-bedding seen throughout the formation. The left portion of stratigraphic section shows geologic eras to which layers are assigned and corresponding timing for deposition by the global Flood according to Austin, *Grand Canyon: Monument to Catastrophe* (1994). Photograph by Tim Helble, inset photo courtesy USGS, graphic after Hill and Moshier (2009).

one used in *Earth's Catastrophic Past*, the new two-volume compilation on Flood geology said to be an update to Whitcomb and Morris' *The Genesis Flood*.[10] Only the Proterozoic (pre-Flood/Creation week) and Paleozoic (early Flood) layers, separated by a clearly visible break known as the Great Unconformity, are visible within Grand Canyon.

Proterozoic Rocks

Grand Canyon's Proterozoic (late Precambrian) rocks consist of (1) igneous and metamorphic rock, sometimes referred to as the crystalline basement, and (2) overlying, tilted sedimentary layers known as the Grand Canyon Supergroup. Because the crystalline basement and the Grand Canyon Supergroup are below the "Cambrian/Precambrian" (Paleozoic/Proterozoic) boundary, they are written off by most Flood geologists as "pre-Flood/Creation week" rocks formed early in the creation week or during the seventeen centuries between Creation and the Flood (using the Ussher timeline). However, abundant evidence exists that the sequence of Proterozoic rock seen in Grand Canyon formed over more than a billion years of Earth history.

The **crystalline basement** consists of metamorphic rock such as schist and gneiss with numerous igneous intrusions. Minerals and structures of the metamorphic rock indicate that sedimentary rock was brought slowly from the surface to depths of 20 to 25 km, squeezed laterally numerous times by thrusting and folding, and brought back up to depths of about 10 km.[11] These depths were not based on biased guesswork—laboratory experiments are increasing geologists' understanding of how different shapes and combinations of minerals reveal the metamorphic history of rock under various pressure-temperature conditions.[12] Igneous intrusions such as granite exhibit mineral structures consistent with slow cooling at depths much greater than where they are found today. Given the depths at which pressure and temperature would have affected metamorphic rock now terminating at the Great Unconformity, it is clear that some 6 miles (10 km) of this rock was removed before the Grand Canyon Supergroup was deposited. This subduction, lateral squeezing, uplift, and subsequent erosion clearly required far more than seventeen centuries.

The **Grand Canyon Supergroup** layers total about 13,000 feet (4,000 m) in thickness, but because they are tilted, highly faulted, and then planed off more or less horizontally at the Great Unconformity, only about 2,000 vertical feet (600 m) are exposed in a given area in the eastern Grand Canyon. Formations in the Grand Canyon Supergroup reflect a variety of depositional settings, including low energy flow (with accompanying ripple marks), mudflat, subaqueous delta, floodplain, tidal flat, shallow subtidal to intertidal, tide/wave affected shoreline, and high energy flow environments. Numerous beds with mud cracks and raindrop imprints are found, indicating long exposure to the atmosphere before subsequent burial. Buried channels can be found in several formations, indicating periods of erosion before subsequent burial. Most also have beds of stromatolites—colonies of blue-green algae (cyanobacteria) in shallow water which built up through the trapping of fine sediments. Some of the evidence for great age of specific formations in the Grand Canyon Supergroup includes the following:

- The **Shinumo Quartzite** consists of sandstones and quartzite (quartz grains solidly cemented with silica).[13] The time required for quartz sand to accumulate and siliceous cement to fill the space between grains to form a substantial layer of erosion-resistant quartzite would be much too long to fit in any young-earth scenario.
- The **Cardenas Lava** has been dated at 1070 ± 70 million years using the Rubidium-Strontium (Rb-Sr) method.[14] Instead of a single lava flow, the Cardenas is a series of basaltic flows with interbedded sandstone layers, which alone would require more than seventeen centuries to form.
- The **Galeros Formation** consists of four members totaling over 4,200 feet (1,300 m) in thickness, each consisting of varying proportions of shale, siltstone, limestone, dolomite, and sandstone. The lowest member—the Tanner Member—fills in recognizable paleotopography cut into the underlying Nankoweap Formation. Quartz grains in sandstone beds of the third member—the Carbon Canyon Member—are set in carbonate, silica, hematite, or chlorite cement or clay matrix, which in itself would indicate a long, diverse history of deposition and lithification.[15]
- The **Kwagunt Formation** includes a dolomite layer with karst features (e.g., cavities, dissolution features), some of which in turn are filled with sandstone and other sedimentary rock. This means enough time elapsed for (1) formation of hardened

limestone, (2) infusion of limestone with magnesium to become dolomite, (3) development of karst features in dolomite through interaction with weak carbonic acid in ground water, and (4) cementation (lithification) of sand and other sediments that worked their way into the solution features to form "rock inside rock."[16] A large block of this karsted dolomite is integrated into the overlying Sixtymile Formation,[17] meaning that enough time elapsed for it to be uplifted, broken off in a landslide, and integrated into a new sediment matrix which then lithified into solid breccia.

Paleozoic Layers

The Paleozoic (early Flood) layers in Grand Canyon span from the Tapeats Sandstone up through the Kaibab formation and are estimated by Austin to total about 4,000 feet in thickness.[18] Paleozoic formations in Grand Canyon reflect a variety of depositional settings, including deep marine, shallow marine, tidal channel, tidal flat, beach, nearshore river valley, floodplain, braided river, and eolian (wind-driven dune) environments. Some of the evidence for great age of specific Paleozoic layers includes the following:

- The **Tapeats Sandstone** has mostly beds of pebbles and coarse sand at its base just above the Great Unconformity.[19] This is not what one would expect as the first deposits of a catastrophic global Flood.
- The **Bright Angel Shale** has beds with abundant trace fossils. These indicate a relatively stable environment and plenty of time for each layer to be colonized and reworked by trilobites and primitive burrowing animals without being immediately crushed under the weight of higher layers.[20]
- The **Muav Limestone** consists mainly of beds of limestone and dolomite of varying thickness.[21] The difference in composition between the fine-grained Bright Angel Shale and carbonates of the overlying Muav Limestone is sufficient to cause several major Grand Canyon springs (e.g., Roaring Springs) to issue at their contact.[22]
- The **Temple Butte Formation** fills numerous channels eroded into the top of the Muav Limestone which are up to 100 feet (30 m) deep and 400 feet (120 m) wide in eastern Grand Canyon. The formation becomes a continuous layer up to 450 feet (140 m) thick to the west. Several marine fossils not found in underlying formations suddenly appear here, including those of gastropods; crinoids; rare corals; small conodonts (eel-like creatures); and armored, plate-mouthed fish known as placoderms.[23]
- The **Redwall Limestone** consists of nearly pure carbonate rock with structure, composition, and fossil content contradicting the idea that it originated as pure calcium carbonate sediments "introduced over the Canyon at the same time the Flood waters became hot from the fountains of the great deep."[24] The Thunder Springs Member of the Redwall is famous for its alternating light and dark bands of fossil-rich chert and carbonate rock.[25] Such numerous, long, and continuous beds of alternating composition are inconsistent with a single catastrophic flood event.
- The **Surprise Canyon Formation** consists of sandstone, siltstone, conglomerate, and carbonate rock filling erosional valleys and karst features (e.g., caves) in the Redwall Limestone. The erosional valleys form a stream network which becomes wider and deeper in a westerly direction, with the deepest measuring 401 feet (122 m).[26] Rocks (clasts) in the conglomerate were derived from the Redwall Limestone, showing that the Redwall was already solid when the Surprise Canyon Formation was deposited.[27] YECs often state how erosional features would be seen in layers if thousands or millions of years passed before deposition of higher layers,[28] and the Surprise Canyon and Temple Butte Formations supply excellent examples of this.
- The **Supai Group** is an incredibly complex series of four formations: the Watahomigi, Manakacha, Wescogame Formations and the Esplanade Sandstone. Shoreline, continental (including eolian), and shallow marine deposition environments are represented, alternating numerous times. Vertebrate footprints have been found in the Wescogame Formation and Esplanade Sandstone.[29]
- The **Hermit Formation** has filled-in channels in its sandstone units with structures commonly associated with point bars in meandering streams. Some buried channels in the Hermit actually cut downward into the Esplanade Sandstone of the Supai Group, indicating deposition was interrupted by a long period of erosion. Vertebrate footprints have also been found.[30]
- The **Coconino Sandstone** (fig. 1, left) is between 65 to 600 feet (20 to 180 m) thick in Grand Canyon and up to 1000 feet (300 m) thick at its southern

boundary on the Mogollon Rim, near Pine, Arizona. The Coconino is composed of cliff-forming, fine-grained, well-rounded quartz sand and small amounts of feldspar, cemented primarily with silica. Irregular cross-bedded sets at an average angle of 25° with thickness up to 66 feet (20 m) can be seen in all exposures (fig. 1, inset).[31] These angled cross beds are truncated by horizontal to slightly dipping planar surfaces which can typically be traced for hundreds of meters. At least five of these planar surfaces exist in the Coconino wall in figure 1, not counting top and bottom contacts with the Toroweap and Hermit Formations. Origin of such planar surfaces in sandstones is still debated, but they are likely some type of erosional feature, because they truncate multiple cross beds. Shorter, "second order" angular surfaces truncate individual cross beds (fig. 1, inset) in a manner associated with migration of small dunes on the upwind and downwind sides of larger, complex dunes.[32] Presence of small pull-apart structures; several types of slump features; small-scale stratification; and low-relief wind ripples as seen in large, broken-off pieces of cross strata are further collective evidence for eolian origin of the Coconino.[33]

Excavations in modern-day dunes reveal the same complex cross beds and other eolian indicators seen in the Coconino.[34] Fossil trackways made by ancient five-toed vertebrates have also been found at several locations, as have spider and millipede tracks and raindrop imprints.[35] To support his case for aqueous deposition of the Coconino, Leonard Brand showed that amphibians in a water tank could leave footprints in fine sand, but his experiments made no attempt to simulate the flow velocities and extreme sediment accumulation rates proposed by YECs in their global Flood scenarios.[36] Any argument for aqueous deposition would have to address all of the evidence for eolian deposition and explain the multiple truncations of irregular cross beds and "second order" surfaces by long, "first order" planar surfaces, while remaining consistent with sediment transport rates required to form the Coconino in a matter of days.

- The **Toroweap Formation** has indicators of a variety of depositional environments, including eolian, tidal/mudflat, and shallow marine and also has beds of evaporites (deposits of minerals slowly precipitated from salt water concentrated by solar evaporation) in some locations.[37]
- The **Kaibab Formation** reflects a complex depositional history involving several alternations between subtidal and shallow marine environments, and also includes some evaporites. Fossil colonies of one brachiopod species—Peniculauris bassi—have been found in exposed bedding planes in their life position (concave up), some with their delicate spines still attached.[38]

Mesozoic Layers

Mesozoic (late Flood) layers resting on top of the Kaibab Formation to the north and east of Grand Canyon start with the Moenkopi and Chinle Formations. There is evidence that up to 5,000 feet (1500 m) of Mesozoic layers existed above the Kaibab Formation well before Grand Canyon was formed. These layers were eroded away from the immediate vicinity of Grand Canyon in association with late Cretaceous (100–65 million years ago) uplift of the region, but still exist as a series of cliffs and plateaus leading up to higher terrain to the north known as the Grand Staircase. Of special note here is the existence of dinosaur footprints and fossils (including nests) in numerous Mesozoic layers.[39]

Cenozoic Layers

Cenozoic (post Flood) layers are found in the highest part of the Grand Staircase in central Utah and surrounding areas. Of special note here is the Green River Formation, which consists of thin couplets of dark organic and light inorganic layers known as varves which record six million years of lake deposition.[40]

Sedimentation Rates As Addressed By Flood Geologists

Even in the face of overwhelming geologic evidence that Grand Canyon's rock layers were not deposited by a single Flood, committed YECs will still be unmoved, because the driving force for them is not science, but a particular approach to biblical interpretation. However, others such as Christians who are undecided about the age of the Earth issue may be persuaded to accept the old age position if they are shown how sediment transport rates would have to be absurdly high to deposit some 4,000 feet of layers in less than half a year, as explained in the remainder of this article.

Flood geologists have written many papers and articles arguing for rapid deposition of various sedimentary formations by a global Flood. However, they generally avoid the quantitative aspects of sediment transport with respect to deposition of Earth's fossil bearing layers, possibly because they have not been taken to task on the subject in a peer-reviewed journal, pro-YEC or mainstream. Flood geologists do address sedimentation rates in other contexts when it can be done in a way that appears to support Flood geology. For example, citing a recent paper on formation of conglomerates in the Crimean Peninsula of the Black Sea, Berthault stated,

> An investigation of sedimentary formation on the Crimean Peninsula (Lalomov, 2007) concluded that the current velocities derived from sedimentary particle analysis would have resulted in the deposition of the entire sedimentary sequence in a very short period of time, rather than the millions of years implied by a stratigraphic analysis using the geological timescale.[41]

However, while Lalomov believed the time to transport sediment forming the conglomerate was dramatically shorter than what he thought might be assumed on the geologic time scale, his approximate calculations showed the duration of sedimentation could be estimated to be on the order of tens of years.[42] This would still be much too long to fit in the global Flood scenario which requires individual formations to be deposited in "a matter of days" as argued by YECs.

For more popular consumption, Andrew Snelling of Answers in Genesis presented a slide at two "Answers for Darwin" conferences (February 2009) with the following:

Answers from Geology? Yes!

- ❖ The average thickness of fossil-bearing sedimentary layers on all the continents is approximately 1,500 meters (5,000 feet).
- ❖ The average sedimentation rate today measured over a *one year* period is c. 100 meters per 1,000 years (0.1 meters per year).
- ❖ The average deposition rate in a modern flash flood measured over *one hour* is c. 1,000 meters per year (c. 0.1 meters per hour).
- ❖ In *one minute* in a modern flash flood the sedimentation rate can be even much higher.
- ❖ Thus 1,500 meters of sediment could easily have accumulated in 5–8 months during the Flood year at flash flood rates.[43]

Snelling's slide seemed to be readily accepted by conference attendees, but its implications stagger the imagination. Here the global Flood is portrayed as the equivalent of innumerable side-by-side, front-to-back flash flood events, somehow overlapping such that sediment was simultaneously deposited over nearly three-fourths of the Earth's current land surface,[44] followed immediately by an equally enormous number of flash deposition events over the same areas, followed by another and another until an average of 1,500 meters has accumulated in five to eight months.[45] Snelling did not specify the source of sediment for such a continuous global depositional event. Clearly, sediment just deposited in one area could not be eroded for deposition in a down-current area; otherwise little or no net accumulation would take place across the globe.

The high vertical sediment accumulation rates called for by Flood geology have been frequently criticized. For example, Weber stated "… the Flood must have been violently dumping several meters' worth of sediment per day"[46] and Neyman came to a similar conclusion.[47] Using Austin's 4,000 foot thickness for the "early Flood" strata and "early Flood" duration of 150 days yields an accumulation rate of 27 feet per day or 1.1 feet per hour. This may not sound too implausible if one's focus is narrowed to a local area and a short time interval. However, if Flood geology is valid, sediment and fossils would not rain down *vertically* from space—they would have been transported *laterally* from one area to the next. When one considers the math of *lateral* sediment transport necessary to form 4,000 feet of sedimentary strata in 150 days over hundreds of thousands of square miles, the implausibility of Flood geology becomes easier to comprehend. This will be illustrated in the following sections using the graphical procedure from *Grand Canyon: Monument to Catastrophe* as a starting point.

A Flood Geology Procedure for Underwater Sand Waves

Mainstream geology has provided compelling evidence for eolian deposition of the Coconino Sandstone. However, desert sand dunes could not exist during a global Flood. Therefore, Flood geologists have expended considerable effort arguing for aqueous origin of the Coconino and against the desert sand dune interpretation.

The overarching goal of *Grand Canyon: Monument to Catastrophe* was to build a case for interpreting

Grand Canyon's layers from the Tapeats Sandstone up to the rim as "early Flood" deposits. Austin needed a way to explain how cross-bedded sandstones in several Grand Canyon formations could be deposited by strong water currents during the Flood. To achieve this, he developed a graphical procedure to illustrate a relationship between underwater sand-wave height, water depth, and water velocity. This procedure, consisting of two side-by-side graphs, was presented as figure 3.12 in *Grand Canyon: Monument to Catastrophe* (fig. 2).

The source for the left-hand graph in figure 2 was equation 2.20 in John R. L. Allen's classic text *Physical Processes of Sedimentation*:

$H = 0.086d^{1.19}$

Where: H = the sand wave height in meters

d = water depth, $0.1 \le d \le 100$ meters[48]

Allen empirically derived this relationship through observations taken in large laboratory flumes. This equation expressed sand-wave height as a function of water depth. However, Austin needed to express water depth as a function of sand-wave height, since he sought to find the depth of Flood waters responsible for producing cross beds of a known height, which he equated to underwater sand-wave height. Therefore, he solved Allen's equation for depth to obtain: $d = 7.86H^{0.084}$

A plot of this equation became the left-hand graph of Austin's flood velocity estimation procedure (fig. 2).

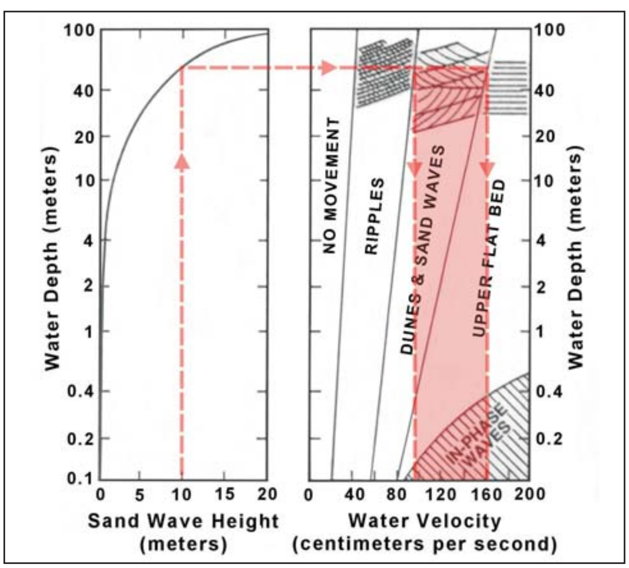

Figure 2. Double graph procedure for estimating the water depth and range of current velocity required to produce sandstone cross beds of a specified height. After Austin, *Grand Canyon: Monument to Catastrophe*, figure 3.12.

Next, a way was needed to relate various types of sediment bed forms created in flowing water—e.g., ripples, dunes and sand waves, and flat beds—to water depth and velocity. Austin found what was needed in figure 8 of a 1980 paper by D. M. Rubin and D. S. McCulloch.[49] This figure was actually two side-by-side graphs—each a semi-log plot of bed phase as a function of depth and velocity. Both graphs were compilations of data from several sources, including Rubin and McCulloch's own observations of sand waves on the floor of San Francisco Bay, which were taken with side-scan radar. The left-hand graph in Rubin and McCulloch's figure 8 was for a range of sand grain size from 0.19 to 0.22 mm and the right-hand graph was for a range of 0.35 to 0.60 mm. Austin selected the left graph—the one for a very narrow range of sand grain size—even though the Coconino is composed of fine sand (0.125 to 0.25 mm), and sandstones in the Supai Group include sand grains up to medium size (0.25 to 0.50 mm).[50] A redrawn version of Rubin and McCulloch's graph with depictions of bedforms in appropriate areas and the horizontal (velocity) axis expanded from about 160 cm/sec to 200 cm/sec became the right-hand graph in Austin's Flood velocity estimation procedure as shown in figure 2.

Before providing instructions on how to use figure 2, Austin mentions that cross beds also exist in sandstones of the Kaibab Formation and Supai Group. He then states that the cross beds of the Kaibab Formation and Supai Group suggest an underwater sand-wave height of "ten meters (33 feet)," while those in the Coconino "could easily be 18 meters (60 feet) high."[51]

Austin explains how to use his double graph procedure using an assumed underwater sand-wave height (H) of 10 meters. First, a line is drawn upward from the 10-meter point on the horizontal (sand-wave height) axis of the left-hand graph until it intersects the curve $d = 7.86H^{0.084}$, as shown in figure 2. In reference to this intersection point, Austin states "the logarithmic scale on the vertical axis indicates that the sand wave formed in water at a depth of 54 meters (180 feet)."[52] Next, a line is drawn from the intersection point across into the right-hand graph until it intersects the left and right boundaries of the "Dunes and Sand Waves" zone. Austin focused on the "Dunes and Sand Waves" zone in the right-hand graph because his goal was to estimate water velocities consistent (in his view) with the cross bed pattern in Grand Canyon sandstones. Vertical lines are then drawn downward from the left and right intersection points. Austin states the left vertical line indicates the minimum current velocity associated with 10 meter sand waves forming at a depth of 54 meters was 90 cm/sec (3 ft/sec). Similarly, the right vertical line indicates a maximum current velocity of 155 cm/sec (5 ft/sec).[53] The shaded area in figure 2 covers the possible range of current velocities that would form dunes and sand waves at a depth of 54 meters.

Austin points out how the graph shows that if the water velocity was too slow (i.e., less than 90 cm/sec), only ripples would form and if the current was too fast (i.e., greater than 155 cm/sec), flat beds would form. Neither ripples nor flat beds would produce any kind of cross-bedding pattern. In other words, the water current must be fast enough to form sand waves, but not too fast so as to keep them from forming. It should be noted that at still higher flows in shallow rivers, upper flat beds give way to upstream migrating bedforms known as in-phase waves or antidunes. If river flow increases still further, antidunes disappear and chutes and pools form. However, Rubin and McCulloch indicate that antidunes and chutes and pools are unlikely under natural conditions in deep water (such as that envisioned by Austin during the Flood) except possibly when turbidity currents occur.[54]

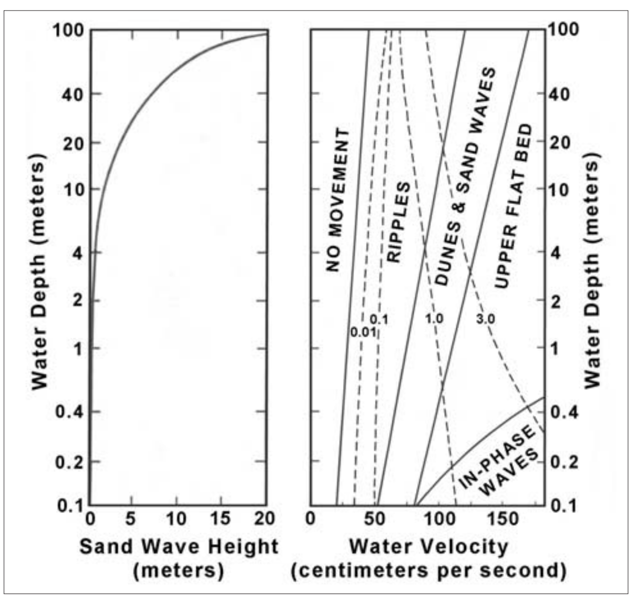

Figure 3. Illustration of how Austin's double graph procedure in *Grand Canyon: Monument to Catastrophe* would appear if it had incorporated the left-hand graph in Rubin and McCulloch's figure 12.

The 90 to 155 cm/sec output from Austin's demonstration of his double graph procedure in *Grand Canyon: Monument to Catastrophe* appears to have taken on a life of its own in young-earth circles. The author has been able to find these two numbers and/or the procedure itself used in ten different locations on the web, some of which are recent posts,[55] three other YEC books,[56] two YEC videos,[57] two secular journal articles (Russian),[58] and one YEC journal article.[59] The double graph procedure was also presented by Andrew Snelling at the previously mentioned "Answers for Darwin" conferences along with the following slide:

Answers from Geology—Sandstones
The Coconino Sandstone

- Averaging 315 feet (96 meters) thick and covering an area of at least 100,000 sq. miles (260,000 sq. km) the sandstone layer contains at least 10,000 cubic miles (42,000 cubic km) of sand.
- Where do we see today 10,000 cubic miles of sand being spread over at least 100,000 sq. miles moving at 3–5 miles per hour?[60]
- NOWHERE!
- But during the Flood this sandstone would have been deposited within just a few days!

Snelling clearly recognized that deposition of all of Grand Canyon's sedimentary rock layers during a year-long Flood would require each layer to be formed in a matter of days. Using a few simple calculations, the next section will show how this leads to a severe challenge for Flood geology.

The Reality Check

When YECs draw on material from the mainstream science community, other information that contradicts the young earth position can often be found in the same cited references. This was the case in Rubin and McCulloch's paper where another graph exists—their figure 12—with the same horizontal and vertical axes as the graph used in *Grand Canyon: Monument to Catastrophe*. Rubin and McCulloch's figure 12 was for a range of sand grains from 0.13 to 0.25 mm, which is more representative of the Coconino, so it would have been a better choice to use in Austin's procedure. Figure 3 shows how the double graph procedure would have appeared had it used Rubin and McCulloch's figure 12, left-hand graph.

The right-hand graph of figure 3 contains some new information, which leads to a major challenge for Flood geology. Similar to figure 2, figure 3 has solid lines separating the zones of no movement, ripples, dunes and sand waves, upper flat bed, and in-phase waves, but it also includes four dashed curves. These curves represent sediment transport rates of 0.01, 0.1, 1.0, and 3.0 kilograms per second per meter (kg/sec/m).[61] None of these curves pass through the dunes and sand waves zone at the 54-meter level, but one might draw a fifth curve in the upper right area which does, to represent a sediment transport rate of perhaps 6 or 9 kg/sec/m. However, this really is not necessary for purposes of this article. We can assume a sediment transport rate ten times higher than 3.0 kg/sec/m and perform a few simple volumetric calculations to find out if this exceptionally high rate could move enough sand to form the Coconino Sandstone in a matter of days. Thirty kg/sec/m is a substantial sediment transport rate, corresponding to a rate of 1.8 metric tons per linear meter of the boundary (perpendicular to the flow) per minute. This is almost 1.0 cubic meter per minute, assuming a sand density of 1900 kg/m^3.

In *Grand Canyon: Monument to Catastrophe*, Austin asks "From where did the sand come, which forms Grand Canyon sandstones?" After addressing this question for other Grand Canyon sandstones, he provides a map (fig. 4, left) showing the area covered by the Coconino Sandstone and "its correlating sandstones" to the east and estimates they cover 200,000 mi^2 (520,000 km^2) and have a volume of 10,000 mi^3 (42,000 km^3). Austin then states,

> Cross beds within the Coconino Sandstone (and the Glorieta Sandstone of New Mexico and Texas) dip toward the south, indicating that the sand came from the north. Along its northern occurrence, the Coconino rests directly on the Hermit Formation. This formation has a finer texture than the Coconino and would not be an ample erosional source of sand grains for the Coconino.
>
> Thus, we cannot look underneath the Coconino for a colossal quantity of sand, we must look northward. However, in southern Utah, where the Coconino thins to zero, the underlying Hermit Formation (and its lateral equivalent, the Organ Rock Shale) continues northward. No obvious, nearby source of Coconino sand grains is known. A very distant source area must be postulated.[62]

With this information, we are almost ready to perform a few simple calculations to see if enough sand could be transported to form the Coconino in a matter of days. However, we still need to know (1) the length of the boundary between the source and depositional areas across which sand would be transported, and (2) the time available for transport before the next higher layer would be deposited. For the boundary length, we will agree with Austin that the sand was transported from the north and assume the boundary was the northern edge of the present-day Coconino

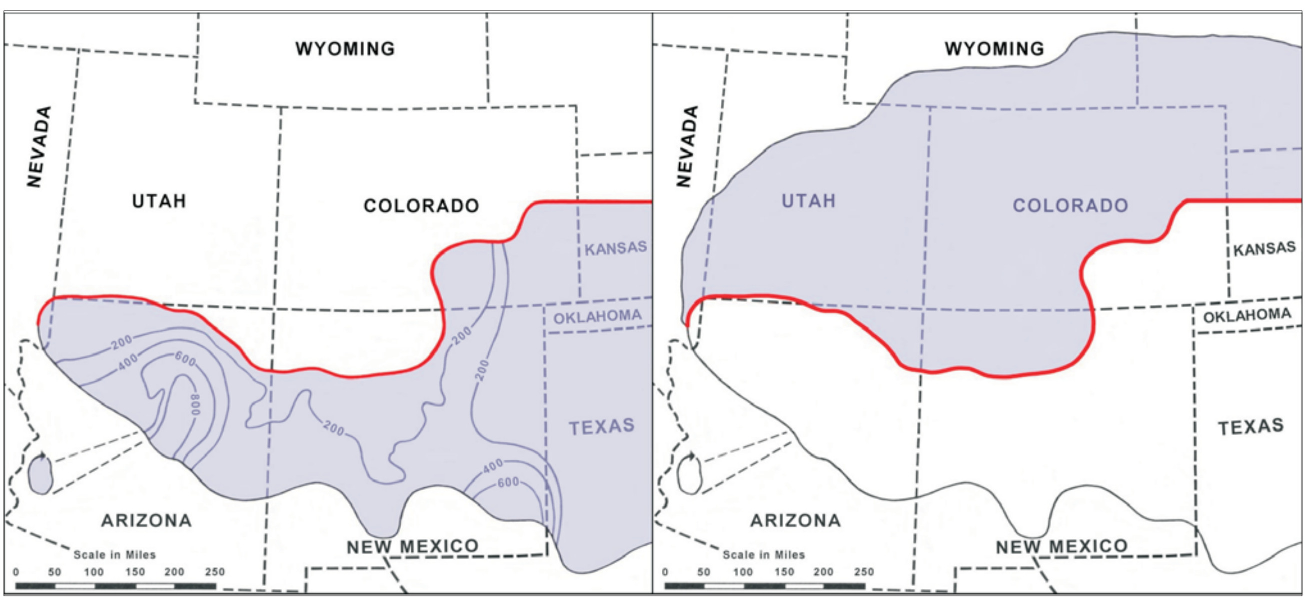

Figure 4. Left: Area covered by the present day Coconino Sandstone and correlated sandstones to the east as described in *Grand Canyon: Monument to Catastrophe*, with northern boundary highlighted. Contour lines indicate sandstone thickness in feet (After Austin, 1994). Right: Hypothetical area to the north covered by perfectly pre-positioned sand (in terms of both timing and location during the Flood), ready to be transported south across the boundary by flood currents into the area of the present day Coconino and its correlated sandstones.

Sandstone and its correlated sandstones to the east as shown in figure 4 (left). The length of this curving boundary is about 1,600 km (1,000 mi). Providing the most generous scenario for Flood geology, we then assume that all of the sand to be transported southward was perfectly positioned in an area immediately to the north of the boundary at just the right time during a global Flood, as hypothetically illustrated in figure 4 (right). We further assume all sand being transported to the south would cross the boundary perpendicularly, even though we know it is curved.

Assuming that massive reservoirs of loose sediment destined to form most of the Earth's sedimentary layers existed before a global Flood may seem far fetched, but it appears this has been considered in young-earth circles. According to a 1994 paper by six well-known Flood geology proponents, such reservoirs could have already existed, ready to be redistributed by a global Flood. The authors explain this assumption as follows:

> We have three reasons for this position: (1) Biologically optimum terrestrial and marine environments would require that at least a small amount of sediment of each type had been created in the creation week; (2) Archean (probable pre-Flood) and Proterozoic sediments contain substantial quantities of all types of sediments; and (3) It may not be possible to derive all the Flood sediments from igneous and/or metamorphic precursors by physical and chemical processes in the course of a single, year-long Flood.[63]

In this statement, the six authors appear to be conceding the Flood would not be able to erode enough pre-Flood rock to produce all the sediment needed to form all of the "early" and "late Flood" sedimentary rock layers.

If we assume that plenty of sand were ready and available for transport from the north into the present-day area of the Coconino Sandstone and that all of the Paleozoic layers were deposited during the 150-day "early Flood" period, then we would need a rough estimate for how many days would be available to deposit the Coconino. If we also assume that the vertical accumulation rate for each "early Flood" layer was the same as the Coconino, we could make our estimation by finding a place where the thickness of all "early Flood" layers has been measured and then dividing up the 150 days in proportion to each layer's thickness. Instead, we will just use the average thickness for the Coconino from Snelling's presentation slide—315 feet—and Austin's estimate for the total thickness of the "early Flood" strata—4,000 feet. The number of days (T_c) to transport enough sand southward across the boundary to form the Coconino is then determined using the simple ratio T_c /150 days = 315 ft/4,000 ft, which yields T_c = 11.8 days (rounded up to twelve days in favor of Flood geology). This would leave 138 days for the other "early Flood" layers.

Of course, other layers cover larger or smaller areas than the Coconino, so each layer would have its own "up-current" boundary and time available for deposition.[64] However, depositing all "early Flood" layers at any location on Earth is under the total time constraint of 150 days, so the above approach is sufficient for estimation purposes. In the following first set of computations, we will use this information to compute how much sand could be transported across the boundary into the present-day area of the Coconino Sandstone.

For a sediment transport rate of 30 kg/sec/m, what mass of sand would cross a 1-meter section of the northern boundary in one day?

$$\frac{30\,kg}{\text{sec}-m} \times \frac{3600\text{ sec}}{hour} \times \frac{24\,hour}{day} = 2.6 \times 10^{6}\ kg\,/\,day - m$$

For a sediment transport rate of 30 kg/sec/m (2.6 x 10⁶ kg/day/m), what mass of sand would cross the entire 1,600 km boundary in twelve days?

$$\frac{2.6 \times 10^{6}\ kg}{day - m} \times 1.6 \times 10^{6}\ m \times 12\,days = 5.0 \times 10^{13}\ kg$$

For a sediment transport rate of 30 kg/sec/m, what volume of sand would cross the 1,600 km boundary in twelve days? (Assume that the density of sand is 1,900 kg/m^3—the range given in textbooks for sandstone is 2,000–2,600 kg/m^3, so 1,900 kg/m^3 is good for loose sand. Note: a lower density is more favorable to Flood geology.)

$$5.0 \times 10^{13}\ kg \times \frac{1\,m^{3}}{1{,}900\,kg} = 2.6 \times 10^{10}\ m^{3} = 26\,km^{3}$$

To form the Coconino in Austin's Flood scenario, 42,000 km^3 of sand would need to be transported across the 1,600 km long northern boundary in twelve days. However, the volume just calculated—26 km^3—is only about 1/1,600 of the required amount. This corresponds to about 2.2 km^3/day, so it would take about fifty-two years to move enough sand across the boundary to form this layer at a sediment transport rate of 30 kg/sec/m (42,000 km^3/2.2 km^3/day ≈ 19,000 days ≈ 52 years).

A second way to demonstrate the problem posed to Flood geology by sediment transport is to calculate the rate needed to move 42,000 km^3 of sand across the 1,600 km boundary in twelve days. The computations are straightforward as shown below.

What total volumetric rate in m³/sec would be required to move 42,000 km³ of sand across any boundary in twelve days?

$$\frac{4.2\times10^{4}\,km^{3}}{12\ days}\times\frac{10^{9}\,m^{3}}{1km^{3}}\times\frac{1day}{86{,}400\ \text{sec}}=4.1\times10^{7}\,m^{3}\ /\ \text{sec}$$

What sediment transport rate in m³/sec/m would be required to move 42,000 km³ of sand across the 1,600 km boundary in twelve days?

$$4.1\times10^{7}\ m^{3}\ /\ \text{sec}\times\frac{1}{1.6\times10^{6}\ m}=25\,m^{3}\ /\ \text{sec}/\ m$$

What sediment transport rate in kg/sec/m would be required to move 42,000 km³ of sand across the 1,600 km boundary in twelve days?

$$25m^{3}\ /\ \text{sec}/\ m\times\frac{1900\,kg}{m^{3}}=4.8\times10^{4}\,kg\ /\ \text{sec}/\ m$$

These calculations indicate a slab of sand 25 m high, 1,600 km wide, and 1,000 km long would have to be continuously sliding southward across the boundary at one meter per second to form the Coconino Sandstone in twelve days. This corresponds to a sediment transport rate of 4.8 x 10^4 kilograms (48 metric tons) per second per meter!

Grand Canyon: Monument to Catastrophe and several YEC books and websites depict cross bed formation as occurring through a series of sand waves formed by water flow, with each wave advancing through erosion of sand grains from the top and deposition on the down-current surface of the wave.[65] However, what has just been computed amounts to something very different—a continuously moving sand slab almost half as high as the 54-meter water depth estimated using Austin's double graph procedure. If it were possible for such a regional-scale sand slab to slide southward into the area of the present-day Coconino sandstone in twelve days, formation of sand waves and cross-beds would obviously be precluded.

Were Calculations Rigged Against Flood Geology?

An initial reaction to these findings might be to suspect that the calculations were set up to produce results unfavorable to Flood geology. Actually, at least nine assumptions were made in favor of the YEC position.

1. **Optimal positioning of 10,000 cubic miles of sand at the right time.** By assuming that the hypothetical area of sand was immediately north of the present-day area of the Coconino Sandstone at just the right time during the Flood, it could be assumed that sand began crossing the boundary into its present-day area at the earliest possible time.
2. **Length of border crossed by "sustained unidirectional currents."** Recall the curved 1,600 km northern boundary in figure 4 and Austin's use of the phrase "sustained unidirectional currents." Since sand would not horizontally compress, the true straight-line boundary, perpendicular to the moving sand slab, would be about 1,300 km long. Taking this factor alone into account, the sand slab would have to be 1600/1300 = 1.2 times as high.
3. **30 kg/sec/meter—a very generous sediment transport rate.** Recall how Austin used Rubin and McCulloch's graph for a sand grain size range of 0.19 to 0.22 mm in his Flood velocity estimation procedure. He stated that his procedure applied to all Grand Canyon sandstones, not just the Coconino. However, such a narrow size range is unrealistic for any of those formations, since they all contain at least some coarser sand. Rubin and McCulloch's figure 8, right-hand graph was for sand grains ranging from 0.35 to 0.60 mm, and could be used to show that a sediment transport rate of 3 kg/sec/m would exist in currents of about 135 cm/sec in the "Dunes and Sand Wave" section at a depth of 54 meters.[66] This indicates that a sediment transport rate of 30 kg/sec/m was more than generous to Flood geology for the first set of computations.
4. **Deposition not delayed by period of scouring at onset of the Flood.** Deposition of "early Flood" sediments was assumed to begin on day one of the Flood, starting with the Tapeats Sandstone. However, Flood geologists say that the Flood began with a period of scouring of "pre-Flood/Creation Week" rock before deposition of "early Flood" layers began.[67] Setting aside a portion of

the 150-day "early Flood" period for this scouring would affect both sets of calculations in directions unfavorable to Flood geology.

5. **Crossing northern boundary equated with depositing the entire Coconino.** Computations were simply presented in reference to sand crossing the 1,600 km northern boundary. No time was allocated for redistribution of sediments according to the contours in figure 4 (left). Since the Coconino is thickest today at its *southern* boundary, impossibly deep sand would have to continue sliding south, well past its current northern boundary. No attempt was made here or in any YEC literature to numerically simulate how a regional-scale sand slab could move into a new area in a matter of days, especially when the height of the sand slab is at least half the depth of the depositing water.
6. **10,000 cubic miles appears to be a low volume estimate.** Simple multiplication of the Coconino's average thickness of 315 feet by its stated area (with correlating sandstones) of 200,000 square miles yields a volume of 11,932 cubic miles. Taking this factor alone into account, the sand slab would have to be 11,932/10,000 = 1.2 times as high.
7. **No accounting for portion that was eroded away.** The Coconino does not lens out to zero thickness along a substantial portion of its boundary. Instead, much of its southern edge is marked by steep cliffs of the Mogollon Rim. A substantially greater original volume for the Coconino would affect both sets of calculations in directions unfavorable to Flood geology.
8. **No break in deposition allocated for the channel fill formations.** Continuous sediment transport was assumed in allocating time for deposition of the Coconino and other Grand Canyon formations. Allowing time for erosion of channel networks to be filled by the Temple Butte and Surprise Canyon Formations would leave less time for deposition during the Flood.
9. **Recent YEC efforts to attribute additional layers to Flood deposition were not considered.** Some Flood geologists have argued for including layers above Austin's "late Flood" and below his "early Flood" layers as Flood deposits. For example, Austin and Wise now consider the Sixty-Mile Formation, the highest formation in the Proterozoic Grand Canyon Supergroup, to be an "early Flood" layer.[68] If the criteria of Oard and Froede were applied,[69] the entire 13,000 ft (4,000 m) thick Grand Canyon Supergroup would be considered "early Flood" layers.[70] Considering any Proterozoic layers to be "early Flood" layers would reduce the number of days allocated to form the Coconino and other Paleozoic layers, further compounding the problems for Flood geology.

Without these nine assumptions, it can be seen how the computed height of the southward moving "sand slab" might easily exceed the depth of water (54 meters) that is supposed to have deposited Coconino sediments in the first place.

Tsunami Transport?

Perhaps recognizing that normal sediment transport processes could not form entire sandstone layers across the globe in a matter of days, Austin invokes repeated tsunamis, triggered by catastrophic movement of lithospheric plates during a global Flood, as mechanisms for transporting huge amounts of sand. In *Grand Canyon: Monument to Catastrophe*, Austin cites Coleman:

> In shallow oceans, tsunami-induced currents have been reported, on occasion, to exceed 500 cm/sec, and unidirectional currents have been sustained for hours …
>
> Such an event would be able to move large quantities of sand, and, in its waning stages, build huge sand waves in deep water. A tsunami provides the best modern analogy for understanding how large-scale Grand Canyon cross beds form. We can imagine how the Flood would cause similar sedimentation in strata of Grand Canyon.[71]

Three significant problems exist with such appeals to tsunami currents. First, checking Coleman's text reveals some selective quoting—many of his key points actually mediate against Austin's case, including the following:

- Nowhere does Coleman cite tsunami currents as unidirectional. He divides tsunamis into two parts—an on-surge and an off-surge. The on-surge primarily plays a softening-up role, affecting *already deposited* shallow water sediment. After the on-surge, an off-surge occurs with a down slope rush of the piled up water which shifts sediments seaward. Note how Coleman described tsunamis as affecting *already deposited* sediment—not as sediment carriers.
- Coleman cites tsunamis as possible causes for building up sequences of chaotic sediments in

> shallow water. Sedimentary rock comprising chaotic sediments appears very different from the nonchaotic, fine-grained, cross-bedded sandstones such as the Coconino.

Second, tsunamis are not an efficient mechanism for global sediment transport. Tsunamis are caused by earthquakes, volcanic eruptions, or landslides deep below the ocean surface and travel at speeds up to 970 km/hr (600 mi/hr). However, they are barely perceptible in the open ocean. It is only when they reach shallow coastal waters that their wave velocity diminishes and their wave height increases until they surge onshore and cause massive destruction of near-shore areas. Also, underwater environments do not always experience massive movements of sand when a tsunami strikes. For example, while the tsunami of December 26, 2004, substantially rearranged areas of underwater sand near some Indo-Pacific islands, scuba divers who were underwater when it struck reported sudden currents and reduced visibility, but they were not suddenly buried by tons of sand.[72]

Third, Flood geologists need to keep their arguments consistent with the very data they are presenting. Austin developed his double graph procedure to estimate the currents necessary to form sand waves and high-angle cross beds in sandstone layers. He concluded that the layers could be formed by "sustained unidirectional currents of 90 to 155 centimeters per second" (2 to 3.5 mi/hr) in "deep water."[73] Immediately following this, Austin suggests that tsunami currents on the order of 500 cm/sec are "the best modern analogy for understanding how large-scale Grand Canyon cross beds form." However, currents anywhere close to 500 cm/sec are clearly outside the velocity range of Austin's double graph procedure (fig. 2).

Daniel Barnette and John Baumgardner have suggested that strong cyclonic water gyres circulated at high latitudes with velocities on the order of 40 to 80 m/sec (90 to 180 mi/hr) during the Flood.[74] In what was probably an attempt to reconcile the rather slow current speeds specified by Austin as necessary to form the cross-bedded Coconino Sandstone and the far stronger global currents proposed by Barnette and Baumgardner, John Morris stated,

> Now we know from observation that water generally moves much more rapidly on the surface than it does at depth. In order for water at a 100-foot depth to move at three to five feet per second, it must be moving at a much greater velocity on the surface.[75]

To explain the discrepancy between the huge volume of the Coconino Sandstone and the minimal amount of sand that could be transported in twelve days by 90 to 155 cm/sec currents, YECs might argue along similar lines by suggesting that a high speed, sediment-laden slurry flowed above a much slower, less turbid water layer consistent with formation of sand waves. However, this explanation would fail at a number of levels, including the following:

- Rubin and McCulloch specified that velocities used in their study were full water column averages of measurements taken near the surface, at mid-depth, and near the bottom.[76] While water velocity is known to decrease with depth, near-surface and near-bottom velocities differing by a factor of 50 are not hydraulically realistic.
- The high water velocities suggested by Barnette and Baumgardner are not physically realistic. Barnette and Baumgardner stated that they were seeking to find "the hydraulic mechanism that was able to transport millions of cubic kilometers of sediment" and "distribute it in widely dispersed layers." However, their mathematical formulation made two assumptions: (1) viscosity of the Flood waters was zero; and (2) density did not need to be accounted for. Both of these assumptions would be invalid for sediment-laden slurries necessary to deposit the Paleozoic (early Flood) and Mesozoic (late Flood) formations in "a matter of days."[77]
- Even if it were possible for a high-density slurry to remain above a less dense, much slower water layer, the sediment would not get to where it is needed at the bottom.

Interestingly, some YECs argue that most sediment transport occurred near the bottom. To explain how dinosaur fossils and footprints could exist in Flood deposits, Oard maintains that "rapid sedimentation would have occurred early in the Flood, especially in deeper, calmer areas" and that circulating gyres proposed by Barnette and Baumgardner would cause local drops in sea level, providing a "powerful force to create the temporary, yet extended, exposures of newly laid Flood sediments."[78] Any pause in the Flood, to expose freshly laid sediments to the atmosphere and to allow floating/swimming dinosaurs to walk ashore, leave footprints, lay egg nests, and die, only compounds the problem for Flood geology because it requires even more absurd average sediment transport rates to make up for the lost deposition time. Several other young earth/Flood geology arguments similarly collapse in the light of the sediment transport problem.

No matter what mechanism one might invent for transporting sediment during the global Flood, including Austin's recently proposed submarine liquefied sediment gravity currents,[79] it should be realized that the absurdly high sediment transport rates needed to deposit a regional-scale layer such as the Coconino Sandstone in a matter of days will always be at odds with the slow water velocities and gradual sediment transport rates needed to form even the most basic cross-bedding structures.

Implications and Conclusion

A few simple calculations have illustrated how the Flood geology interpretation of the Coconino Sandstone is completely untenable. The National Academy of Science captured the essence of the matter when they stated that Flood geology "defies all geological observations and physical principles concerning sedimentation rates and possible quantities of suspended solid matter." These findings would seem to be a good illustration of Francis Collins' statement in *The Language of God*:

> But the claims of Young Earth Creationism simply cannot be accommodated by tinkering around the edges of scientific knowledge. If these claims were actually true, it would lead to complete and irreversible collapse of the sciences of physics, chemistry, cosmology, geology, and biology.[80]

There is nothing particularly unique about the Coconino Sandstone or the sequence of Paleozoic strata in Grand Canyon—sandstones are common across the globe and total thickness of "early Flood" strata is much greater in other areas. For example, as Daniel Wonderly pointed out, the total thickness of sedimentary rock in the Appalachian Mountains of eastern West Virginia and western Virginia is between 20,000 to 35,000 feet.[81] Forming those layers in the 150-day "early Flood" period would require sediment transport rates substantially greater than anything calculated in this article.

Flood geologists seem to need fantastically huge sediment transport rates when it is convenient for their explanations, but at other times during the same global Flood, they need slow rates to allow for intricate features such as complex cross beds and vertebrate footprints. It becomes clear that Flood geology is not just another way of, as frequently maintained by YEC leaders, "looking at the same data and coming to different conclusions." It also becomes clear that the YEC ministries are placing Christians in the unfair position of having to choose between biblical authority and straightforward reasoning from observation of God's created world.

Flood geologists are currently involved in multiyear activity known as the Flood Activated Sedimentation and Tectonics (FAST) project, with several papers anticipated for publication in the near future.[82] There is no doubt these papers will present more "evidence" for aqueous or catastrophic Flood deposition for various sedimentary formations, including the Coconino Sandstone.[83] Rather than endlessly sparing with YECs over whether a specific formation indicates aqueous/catastrophic or gradual deposition (or both), it might be more profitable to focus on the sediment transport problem, which is the Achilles' heel of Flood geology. Flood geologists' recent efforts to engage in mainstream science are laudable. However, the sediment transport problem will prevent their central thesis from ever being accepted in the scientific community and the reason for this should be understood in the Christian community.

Acknowledgments

The author would like to credit Greg Neyman, maintainer of the "Answers in Creation" website, as originator of the idea that "90 to 155 cm/sec water currents" could never transport anywhere near enough sand to form the Coconino in a few days. The author would also like to thank Carol Hill for her encouragement to write this article and for her review of the first draft.

Notes

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2For example, at the 2005 annual meeting of the Geological Society of America (GSA), a session was held entitled "Is it Science? Strategies for Addressing Creationism in the Classroom and the Community." See http://gsa.confex.com/gsa/2005AM/finalprogram/session_16171.htm (accessed Dec. 8, 2010).

[3]S. A. Austin, ed., *Grand Canyon: Monument to Catastrophe* (Santee, CA: Institute for Creation Research, 1994), 33–5.

[4]G. Neyman, "Creation Science Rebuttals *Creation Magazine:* Coconino Sandstone (Startling Evidence for Noah's Flood)," www.answersincreation.org/coconino.htm (accessed June 6, 2010).

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[12]Ibid., 36; and D. A. Young and R. F. Stearley, *The Bible, Rocks, and Time* (Downers Grove, IL: InterVarsity Press, 2008), 337–40. Actually, this is covered in basic geology textbooks, e.g., see J. Grotzinger, T. H. Jordan, F. Press, and R. Siever, *Understanding Earth*, 5th ed. (New York: W. H. Freeman and Company, 2007), 141–7.

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[18]Austin, *Grand Canyon: Monument to Catastrophe*, 67.

[19]L. T. Middleton and D. K. Elliott, "Tonto Group," in Beus and Morales, eds., *Grand Canyon Geology*, 92–4, 101.

[20]Ibid., 94–5, 103-4.

[21]Ibid., 95–6, 104–5.

[22]National Park Service, *Water Resources Management Plan* (Grand Canyon National Park, 1984), 15–6.

[23]S. S. Beus, "Temple Butte Formation," in Beus and Morales, eds., *Grand Canyon Geology*, 107–14.

[24]Austin, *Grand Canyon: Monument to Catastrophe*, 72.

[25]S. S. Beus, "Redwall Limestone and Surprise Canyon Formation," in Beus and Morales, eds., *Grand Canyon Geology*, 115–23. According to Beus, the chert layers originated as bryozoan-rich wackestones (a specific type of sandstone) and mudstones which became silicified.

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[27]S. S. Beus, "Megafossil Paleontology of the Surprise Canyon Formation, Chapter E" in Billingsley and Beus, eds., "Geology of the Surprise Canyon Formation of the Grand Canyon, Arizona," 69.

[28]Andrew Snelling, *Answers Academy, The Rocks Cry Out: The Earth Is Young!* Taught by Terry Mortenson, Answers in Genesis, 2009, video. www.answersingenesis.org/media/video/ondemand/aa-rocks-cry/aa-rocks-cry (accessed November 2, 2010.

[29]R. C. Blakey, "Supai Group and Hermit Formation," in Beus and Morales, eds., *Grand Canyon Geology*, 136–62.

[30]Ibid., 147–9.

[31]L. T. Middleton, D. K. Elliott, and M. Morales, "Coconino Sandstone," in Beus and Morales, eds., *Grand Canyon Geology*, 171–5.

[32]Ibid., 176–7.

[33]Ibid., 171–4.

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[36]L. R. Brand, "Fossil Vertebrate Footprints in the Coconino Sandstone (Permian) of Northern Arizona: Evidence for Underwater Origin," *Geology* 19 (1991): 1201–4. The current in Brand's water tank was 8 cm/sec.

[37]C. E. Turner, "Toroweap Formation," in Beus and Morales, eds., *Grand Canyon Geology*, 180–95.

[38]R. L. Hopkins and K. L. Thompson, "Kaibab Formation," in Beus and Morales, eds., *Grand Canyon Geology*, 196–211.

[39]YECs propose it was possible for freshly deposited areas of sediment to be exposed long enough for dinosaurs that managed to stay afloat for months during the Flood (e.g., on debris) to walk ashore, lay eggs, and/or be buried by subsequent onslaughts of Flood sediments—e.g., see M. J. Oard, "Dinosaur Tracks, Eggs, and Bonebeds," in M. J. Oard and J. K. Reed, *Rock Solid Answers* (Green Forest, AR: Master Books, 2009), 245–58.

[40]This is disputed by YECs, who argue that multiple runoff events during a year could cause more than one couplet to appear each year, e.g., see M. J. Oard, "Do Varves Contradict Biblical History?" in Oard and Reed, *Rock Solid Answers*, 125–48.

[41]G. Berthault, "Time Required for Sedimentation Contradicts the Evolutionary Hypothesis," *Creation Research Society Quarterly* 46, no. 4 (2010): 266; and A. V. Lalomov, "Reconstruction of Paleohydrodynamic Conditions during the Formation of Upper Jurassic Conglomerates of the Crimean Peninsula," *Lithology and Mineral Resources* 42, no. 3 (2007): 277.

[42]A. V. Lalomov, Personal Communication, 2010. Lalomov also informed me that Berthault characterized his findings better than the Russian-to-English translation in the *Lithology and Mineral Resources* article.

[43]Video: *Answers for Darwin – Refuting 200 Years of Evolution*, The Word for Today, 2009.

[44]S. Boggs Jr., *Principles of Sedimentology and Stratigraphy* (Upper Saddle River, NJ: Pearson Prentice Hall, 2006), xvii. According to this reference, "nearly three fourths of Earth's land surface and most of the ocean floor is covered by sedimentary rock and sediments."

[45]Some Flood geologists appear to hold that Flood deposition occurred over a longer duration—e.g., Austin, *Grand Canyon: Monument to Catastrophe*, 77.

[46]C. G. Weber, "The Fatal Flaws of Flood Geology," *Creation/Evolution* 1 (1980): 24–37.

[47]G. Neyman, Creation Science Book Review, "*Grand Canyon: Monument to Catastrophe*, Chapter 4: A Creationist View of Grand Canyon Strata," www.answersincreation.org/bookreview/monument/c4.htm (accessed June 6, 2010).

[48]J. R. L. Allen, *Physical Processes of Sedimentation* (London: Unwin University Books, 1970), 78. Ironically, Allen cites the Coconino as being eolian in origin on page 115 of this book. Allen has since replaced *Physical Processes of Sedimentation* with *Principles of Physical Sedimentology* (Caldwell, NJ: The Blackburn Press, 1985), but equation 2.20 was not included in the new book.

[49]D. M. Rubin and D. S. McCulloch, "Single and Superimposed Bedforms: A Synthesis of San Francisco Bay and Flume Observations," *Sedimentary Geology* 26 (1980): 207–31.

[50]McKee, "Ancient Sandstones Considered to be Eolian" in *A Study of Global Sand Seas*, 199; Middleton, Elliott, and Morales, "Coconino Sandstone," in Beus and Morales, eds., *Grand Canyon Geology*, 171; and R. C. Blakey, "Supai Group and Hermit Formation," in Beus and Morales, eds., *Grand Canyon Geology*, 140.

[51]Austin, *Grand Canyon: Monument to Catastrophe*, 34.

[521]The 54-meter "depth" obtained by reading the graph may strike the scientifically trained reader as excessive precision, but it was actually calculated from the equation in Allen's *Physical Processes of Sedimentation* solved for depth. The reader of *Grand Canyon: Monument to Catastrophe* is not informed how this was done.

[53]Austin, *Grand Canyon: Monument to Catastrophe*, 34–5.

[54]Rubin and McCulloch, "Single and Superimposed Bedforms: A Synthesis of San Francisco Bay and Flume Observations," 224.

[55]The ten URLs are as follows (all accessed June 6, 2010):

From the Answers in Genesis website:

1. www.answersingenesis.org/articles/am/v3/n3/transcontinental-rock-layers;
2. www.answersingenesis.org/tj/v11/i1/sedimentation_reply.asp;
3. www.answersingenesis.org/articles/am/v3/n4/fast-furious;
4. www.answersingenesis.org/creation/v15/i1/flood.asp (This article assumes a sand-wave height of 20 meters, which yields a velocity range of 95 to 165 cm/sec)

From the Creation Ministries International (CMI) website (formerly on the Answers in Genesis website, but transferred over to the CMI website after the two ministries split):

5. http://creation.com/cmi-presents-geological-misinformation;
6. http://creation.com/the-indoctrinator

From other young earth creationist websites:

7. www.kolbecenter.org/wilder.geocolumn.pdf;
8. http://creationanswers.net/newsletters/newslet00_02/crans_v3.1.0402.pdf;
9. http://creationwiki.org/Coconino_sandstone_was_deposited_underwater_ %28Talk.Origins%29;
10. www.sedimentology.fr/ (click on "Paleohydraulics" in the left margin).

[56]Morris, *The Young Earth*, 101; Snelling, "What Are Some of the Best Flood Evidences?" in *The New Answers Book* 3, 289; and Snelling, *Earth's Catastrophic Past*, 506–8, 1081.

[57]Video: *Answers for Darwin—Refuting 200 Years of Evolution*, The Word for Today, 2009; and Video: *Grand Canyon: Testimony to the Biblical Account of Earth's History*, Answers in Genesis, 2009.

[58]G. Berthault, "Analysis of Main Principles of Stratigraphy on the Basis of Experimental Data," *Lithology and Mineral Resources* 37, no. 5 (2002): 445 and G. Berthault, "Sedimentological Interpretation of the Tonto Group Stratigraphy (Grand Canyon Colorado River)," *Lithology and Mineral Resources* 39, no. 5 (2004): 507.

[59]G. Berthault, "Time Required for Sedimentation Contradicts the Evolutionary Hypothesis," *Creation Research Society Quarterly* 46 (Spring 2010): 266. (Berthault never attributes Austin for combining the plot of Allen's equation with Rubin and McCulloch's graph to form the double graph procedure).

[60]This apparently reflects some confusion in units—Snelling was using Austin's double graph for a sand-wave height of 20 meters. This yields a velocity range of 95 to 165 cm/sec, which is about 3.1 to 5.4 ft/sec or 2.1 to 3.7 mi/hr. At some point, Snelling began stating the range was 3 to 5 mi/hr when it was really 3 to 5 ft/sec.

[61]A sediment transport rate of 1 kilogram per second per meter is 1 kilogram of sand crossing a 1 meter long line perpendicular to the direction of flow (in the horizontal plane) every second. A good way to visualize this is to consider a meter stick on the ground with a pile of sand on one side. If the sediment transport rate was 1 kg/sec/m, one kilogram of sand (or a little over ½ liter, assuming a sand density of 1900 kilograms per cubic meter) would be crossing the meter stick every second.

[62]Austin, *Grand Canyon: Monument to Catastrophe*, 36.

[63]S. A. Austin, J. R. Baumgardner, D. R. Humphreys, A. A. Snelling, L. Vardiman, and K. P. Wise, "Catastrophic Plate Tectonics: A Global Flood Model of Earth History," Proceedings of the Third International Conference on Creationism, 1994, http://static.icr.org/i/pdf/technical/Catastrophic-Plate-Tectonics-A-Global-Flood-Model.pdf (accessed June 6, 2010).

[64]Lateral sediment transport required to form the Tapeats Sandstone in a matter of days would be especially problematic for Flood geology, since YECs often point out how it is part of the Sauk Megasequence, which covers much of North America—e.g., see A. A. Snelling, "Transcontinental Rock Layers: Flood Evidence Number 3," www.answersingenesis.org/articles/am/v3/n3/transcontinental-rock-layers (accessed June 6, 2010).

[65]Austin, *Grand Canyon: Monument to Catastrophe*, 33. See also G. Berthault, "Analysis of the Main Principles of Stratigraphy on the Basis of Experimental Data," www.sedimentology.fr/ (accessed June 6, 2010); and A. A. Snelling and S. A. Austin, "Startling Evidence for Noah's Flood: Footprints and Sand 'Dunes' in a Grand Canyon

Sandstone," www.answersingenesis.org/creation/v15/i1/flood.asp (accessed June 6, 2010).

[66]Rubin and McCulloch, "Single and Superimposed Bedforms: A Synthesis of San Francisco Bay and Flume Observations," 218.

[67]Snelling, *Earth's Catastrophic Past*, 707, 713–21 and Austin, *Grand Canyon: Monument to Catastrophe*, 45–7. Flood geologists often cite scouring of the Channeled Scablands in eastern Washington by the Lake Missoula flood and Glen Canyon Dam spillways during the 1983 flood as examples of how this would occur (see Austin, *Grand Canyon: Monument to Catastrophe*, 46–7, 104–7).

[68]S. A. Austin and K. P. Wise, "The Pre-Flood/Flood Boundary: As Defined in Grand Canyon, Arizona and Eastern Mojave Desert, California," in R. E. Walsh, ed., *Proceedings of the Third International Conference on Creationism* (Pittsburgh, PA: Creation Science Fellowship, 1994), 37–47.

[69]M. Oard and C. Froede Jr., "Where is the Pre-Flood/Flood Boundary?" *Creation Research Society Quarterly* 43, no. 1, (2008): 24–39. The precise words of the authors were "Based on these revised criteria, we would favor the placement of the (Pre-Flood/Flood) boundary near or at the contact between the igneous and metamorphic basement rocks and the overlying sedimentary rocks, whether Precambrian or Phanerozoic." Setting aside the sediment transport problem for the moment, the problem with counting the Grand Canyon Supergroup as Flood layers is that some 13,000 feet of strata would have to be deposited, tilted, and then mostly eroded away (except for where they can be found today in eastern Grand Canyon) during the early phase of the global Flood.

[70]At the close of the Sixth International Conference on Creationism on August 6, 2008, Andrew Snelling gave a presentation entitled "The Creation Model: Its Past, Its Present and Its Necessary Future," which included a slide with the following as one of its sub-bullets: "Even nearly five decades after *The Genesis Flood* we still have no comprehensive model of earth history explaining the geologic (strata and fossil) record that includes general agreement on Creation Week rocks, pre-Flood/Flood and Flood/post-Flood boundaries."

[71]Austin, *Grand Canyon: Monument to Catastrophe*, 35 quoting from P. J. Coleman, "Tsunami Sedimentation," in R. W. Fairbridge and J. Bourgeois, eds., *The Encyclopedia of Sedimentology* (Stroudsburg, PA: Dowden, Hutchinson and Ross, 1978), 828–31. During a presentation entitled "Catastrophic Plate Tectonics" at the 2009 Seattle Creation Conference in Mukilteo, WA, Steve Austin stated that the tsunamis were caused by magnitude 8 to 9 earthquakes during the global cataclysm (see www.nwcreation.net/videos/Catastrophic_ Plate_ Tectonics.html, accessed June 6, 2010).

[72]A. Desiderato, "I Was One of the Lucky Ones. I Lost Nothing," UCLA Center for Southeast Asian Studies Newsletter, posted February 12, 2005, www.international.ucla.edu/cseas/article.asp?parentid=20716 (accessed June 6, 2010); "American Diver Underwater During Catastrophe," posted December 29, 2004, www.cnn.com/2004/US/12/28/tsunami.diver/index.html (accessed June 6, 2010); G. S. Stone, "Tsunami and Coral Reefs: Extent of the Damage," *New England Aquarium Member's Magazine* 39, no. 1 (Winter 2006): 9–11, www.neaq.org/documents/conservation_and_research/global_change/aqualog_tsunami.pdf (accessed June 6, 2010).

[73]Austin, *Grand Canyon: Monument to Catastrophe*, 34–5.

[74]D. W. Barnette and J. R. Baumgardner, "Patterns of Ocean Circulation over the Continents during Noah's Flood," in R. E. Walsh, ed., *Proceedings of the Third International Conference on Creationism* (Pittsburgh, PA: Creation Science Fellowship, 1994), 76–88. See also R. Prabhu, M. F. Horstemeyer, and W. Brewer, "Ocean Circulation Velocities over the Continents during Noah's Flood," in A. A. Snelling, ed., *Proceedings of the Sixth International Conference on Creationism* (Pittsburgh, PA: Creation Science Fellowship and Dallas, TX: Institute for Creation Research, 2008), 247–54.

[75]Morris, *The Young Earth*, 101.

[76]Rubin and McCulloch, "Single and Superimposed Bedforms: A Synthesis of San Francisco Bay and Flume Observations," 217.

[77]Barnette and Baumgardner disregarded fluid density because they assumed that the simplified 2D equations could be used to describe flow in both the atmosphere and oceans and disregarded viscosity because the equations assumed an ideal fluid. These simplifying assumptions made the equations fairly easy to solve (see Barnette and Baumgardner, "Patterns of Ocean Circulation over the Continents during Noah's Flood," 78).

[78]M. J. Oard, "Dinosaur Tracks, Eggs, and Bonebeds," in Oard and Reed, *Rock Solid Answers*, 246–7.

[79]S. A. Austin "Submarine Liquefied Sediment Gravity Currents: Understanding the Mechanics of the Major Sediment Transportation and Deposition Agent during the Global Flood" (paper presented at the Fourth Creation Geology Conference, Cleveland, GA, July 28–30, 2010), www.cedarville.edu/event/geology/2010_proceedings.pdf (accessed Dec. 9, 2010).

[80]F. S. Collins, *The Language of God* (New York: Free Press, 2006), 173–4.

[81]D. E. Wonderly, *Neglect of Geologic Data – Sedimentary Strata Compared to Young Earth Creationist Writings* (Hatfield, PA: Interdisciplinary Biblical Research Institute, 2006), 40, www.asa3.org/ASA/resources/Wonderly2006.pdf (accessed June 6, 2010).

[82]L. Vardiman, "A FAST Summer in the Grand Canyon and Wyoming," *Acts & Facts* 36, no. 8 (2007): 6. www.icr.org/article/fast-summer-grand-canyon-wyoming/ (accessed June 6, 2010).

[83]For example, see J. H. Whitmore and R. Strom, "Sand injectites at the base of the Coconino Sandstone, Grand Canyon, Arizona (USA)," *Sedimentary Geology* 230 (2010): 46–9; S. P. Cheung, R. Strom, J. H. Whitmore, and P. Garner, "Occurrence of Dolomite Beds, Clasts, Ooids and Unidentified Microfossils in the Coconino Sandstone, Northern Arizona" (paper presented at the annual meeting of the Geological Society of America, Portland, OR, October 18–21, 2009), http://gsa.confex.com/gsa/2009AM/finalprogram/abstract_161247.htm (accessed June 6, 2010); J. H. Whitmore and R. Strom, "Petrographic Analysis of the Coconino Sandstone, Northern and Central Arizona" (paper presented at the annual meeting of the Geological Society of America, Portland, OR, October 18–21, 2009), http://gsa.confex.com/gsa/2009AM/finalprogram/abstract_159012.htm (accessed June 6, 2010).