Aug 15, 2024 published
Aug 15, 2024 online
Aug 15, 2024 modified
Aug 25, 2024 accessed

The Tonto Deformation

Stephen Mitchell and **Kennen Tilman**

https://doi.org/10.54739/k1y8

The third contrasting view separating the YEC views proposed by Dr. Snelling from most geologists' understanding regards how these rocks were deformed. Geologists recognize that rocks can be deformed by brittle mechanisms, such as faulting and fracturing or by ductile mechanisms that produce folds. If you want to understand the difference, you can perform a simple experiment. First, drop a ball of soft clay from a few feet up onto a concrete floor. Next, drop a fine porcelain plate onto the same concrete floor. Both will have different shapes after the fall. The clay may be slightly cracked but much of the change will be ductile. In contrast, the porcelain plate will be shattered or brittlely deformed. The Tonto units show evidence of both. All agree that the folds in question here were folded by ductile mechanisms, but the differences include the specific mechanisms involved and how much time was required for the folding.

The consensus view is that folding in the Tonto formations took place over thousands to millions of years, while YEC timelines demand that it took place over a much shorter time period. Today, the rocks that make up the Tonto group are not loose sediment but hardened or lithified stone. Since at least 2009, Snelling[1] has proposed that the folding of the Tapeats sandstone in the Grand Canyon occurred before the sediments were lithified. This kind of deformation is commonly known as soft-sediment deformation. Snelling's present studies began in 2013 with a research proposal specifically designed to examine the Tonto sediments for evidence related to the timing of the folding in these units.[2]

This article is in a series examining the claims in these three articles by young earth creationist, Andrew Snelling:

Snelling, Andrew. "The Petrology of the Tapeats Sandstone, Tonto Group, Grand Canyon, Arizona." *Answers Research Journal* 14 (2021): 159–254.

Snelling, Andrew. "The Petrology of the Bright Angel Formation, Tonto Group, Grand Canyon, Arizona." *Answers Research Journal* 14 (2021): 303–415.

Snelling, Andrew. "The Petrology of the Muav Formation, Tonto Group, Grand Canyon, Arizona." *Answers Research Journal* 15 (2022): 139–262.

In the articles reviewed here, Snelling[3] has taken a detailed look at the petrology of the Tonto Group sediments in the Grand Canyon, focusing on zones where the rocks have been folded. Although these first publications reviewed here are mostly dedicated to lithologic descriptions and depositional environments, Snelling argues that all observations to this point are consistent with rapid deposition and deformation of the sediments during Noah's global flood cataclysm. He does state that he found no evidence for metamorphism of the sedimentary rocks, but does not directly address grain-scale deformation. He indicates that future work will compare the petrology of the rocks outside and inside the folded areas to examine the grain-scale deformation mechanisms to determine how the rocks were deformed. The newest publication, "The Carbon Canyon Fold, Eastern Grand Canyon, Arizona" published in 2023 deals specifically with one of the sampled folds. No doubt more publications will follow. In this latest article, which we plan to discuss in the future, Snelling has done a lot of good work and made many good observations in his analysis of the deformation of the Carbon Canyon fold. For now, we simply want to state that while the technical descriptions are usually valid, the expectations or criteria that he presents to support his conclusions are questionable. Deformation takes many forms and degrees and is impacted by many factors, and we believe that the observations are better explained by slow deformation over a long period of time.

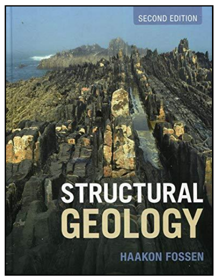
Geologists certainly agree that lithified rocks cannot be folded over a few thousand years, but does this change if longer periods are involved? 'Solid as a rock' is an expression of strength, but time can change the ability of a substance to resist deformation. We see this in everyday life. We (Steve) have a lot of boxes in our attic. The cardboard boxes can be stacked in any order and the cardboard will seem to be firm and stable. However, experience says that what is stable in the few minutes that it takes to stack them is not necessarily stable for the long term. We have demonstrated this by stacking heavy boxes on top of light boxes and coming back a few months or years later. We have often found that the "stable" solid cardboard boxes have collapsed. The cardboard ended up folded and crumpled because stress was applied to it over time. The cardboard was not chemically altered or "metamorphosed", but over a period of time, it was deformed. Rocks that are folded over long periods of time do not simply flow like a viscous fluid, but other mechanisms allowed the folding to take place.

1. Snelling 2009a; 2009b

2. Snelling, Andrew A., n.d.

3. Snelling 2021b; 2021a; 2022

The mechanisms by which unlithified and lithified sediments fold at low pressures and temperatures are very different at both grain scale and bed scale, and also typically produce folds with different geometries. Moreover, folding of these two different types of sediments occurs at very different rates. Folding of soft sediments can happen as quickly as hours to days to years. Folding of lithified sediments, in contrast, takes hundreds of thousands to millions of years. Of course, unlithified and well lithified sediments are end members on a continuum and deformation rates and mechanisms will depend on the lithologies involved and the degree of lithification. For simplicity, let's first consider these end members, but recognize that the Tonto units are not at the extremes either in terms of the degree of lithification or the amount of deformation evidenced.



Evaluating Snelling's proposal and evidence will mean understanding a bit about how sediments are folded and a bit about the structures in the Grand Canyon area. Looking first at the grain scale, unlithified, or "soft," sediments deform at the grain scale primarily by a mechanism known as grain boundary sliding,[4] where the uncemented individual grains can "slide" past one another as they rigidly translate and rotate, typically resulting in compaction, dewatering, and reduced porosity. Fractures that cut across layers or multiple grains are uncommon because of the lack of coherency. Although some fracturing of grains can occur at point-to-point grain contacts, fracturing of grains is typically infrequent or absent.

In contrast, in strongly lithified sediments, individual grains are not free to move relative to one another due to the cementation. As a result, in order for the sediments to deform, the grains and/or the cements have to deform.[5] As the degree of cementation increases, grains are less and less able to rotate freely and they are broken and shattered. In contrast to soft sediment deformation, fractures can cut across multiple grains or even multiple layers. Fractures with shear (displacement along a zone) typically exhibit cataclasis, the crushing of rock that is typified by fracturing of grains, grain-size reduction, and compaction. In the Tonto Group folds, we see moderate deformation and perhaps moderate lithification (less extensive quartz cementation than sometimes found),[6] we will look for evidence of grain-scale deformation, but do not expect it to be ubiquitous. At the bed scale, there are also significant differences in the deformation of unlithified and lithified sediments. Lithification not only increases the coherency of the beds so that beds behave as integrated rocks, but also enhances and localizes mechanical discontinuities at bed boundaries, especially between beds with significant differences in grain size and composition (e.g., sandstone and mudstone). As a result, flexural slip (i.e., slip localized along bedding planes; like the pages of a book sliding past each other when the book is bent) commonly occurs during folding of more lithified sediments at relatively low pressure/temperature conditions (Burg 2018). Evidence for flexural slip includes bedding parallel veins, offset along bedding planes of pre-existing features that cut across bedding (e.g., fractures and veins) and slickensides. Slickensides are surfaces with linear striations formed by friction and/or mineral growth that show the direction of slip. In flexural-slip folds, the linear striations are typically roughly perpendicular to the axis of the fold. Furthermore, because of the increased bed coherency due to lithification, the more competent beds (typically sandstones) tend to maintain bedding thickness and accommodate stretching by fracturing perpendicular to bedding, while the less competent beds (like mudstones) will exhibit more ductile deformation, allowing changes in bedding thickness, particularly in fold hinges where space problems occur.

In contrast, unlithified beds are relatively incoherent and the mechanical differences between beds and at bedding contacts are diminished. Muds and sands will behave similarly. As a result, the deformation is more uniformly distributed, slickensides are unlikely to form, and bedding thickness changes occur in all lithologies. The resulting folds commonly have a "soupy" appearance such as might develop in folding damp clay or mud (Figure 9) with significant thickness changes and varying fold amplitudes and wavelengths. Fluid escape features (e.g., flame structures) are also commonly associated with soft-sediment deformation due to the high porosity and rapid compaction during deformation, whereas brittle faults and fractures are absent. Snelling[7] says that fracturing in the hinges should be expected, but fractures are brittle deformation features.

In a continuum that ranges between totally unlithified sediments to highly lithified, and highly deformed to gently deformed, where would the folding in the Tonto group fall? We have identified the criteria that can be used to differentiate between folding of soft (unlithified) sediments, which can occur very rapidly, and folding of lithified sediments, which can only occur over a very long period of time. Now let's consider the observations that have been made of the folds in the Grand Canyon in general, and in the Tonto Formation in particular. Even moderately lithified and moderately deformed sediments would require long periods of time to deform. Before we look at these particular folds however, it's useful to understand the regional context of those folds, so let's start there.

Figure 9. Soft sediment deformation example showing how both sand and shale beds changed in thickness as the folding took place. (Photo by Dan Hobley. Creative Commons Attribution-Share Alike 4.0 International license from Wikipedia)

4. Fossen 2010, 209
5. Fossen 2010, 204-5
6. Notice that the Tapeats is referred to as a sandstone, as opposed to a quartzite. Other units in the Cambrian are more extensively cemented and referred to as quartzite, though they are not necessarily metamorphosed.
7. Snelling 2023, Abstract

Regional Context

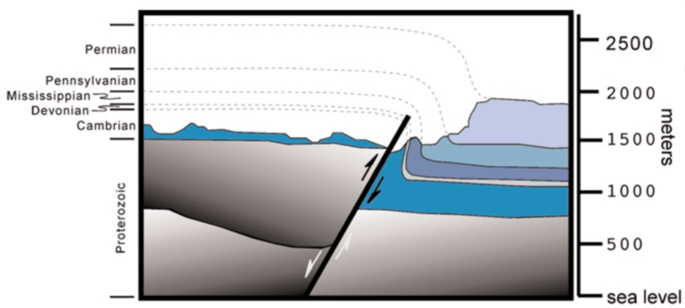


Figure 12. Cross section showing EKM fault-fold relationships (Tindall, 2000). Note the dashed lines that show the interval that has been eroded away. The downthrown block has steeply dipping beds and tight folds.

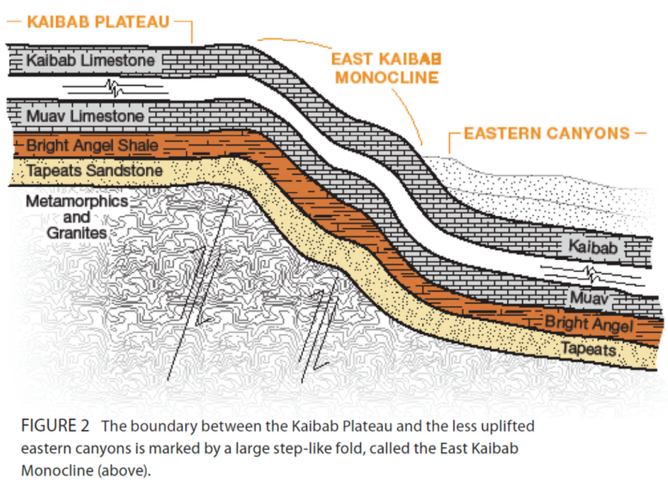


Figure 11. Snelling (2009b) showing his understanding of the development of the folding. Notice that the Tapeats Sandstone is shown draping gently over the faults that died out before the top of the "Metamorphics and Granites".

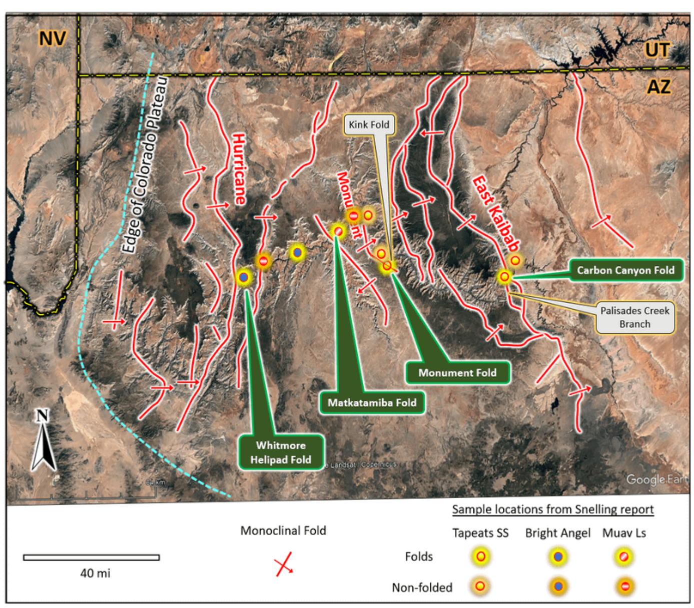
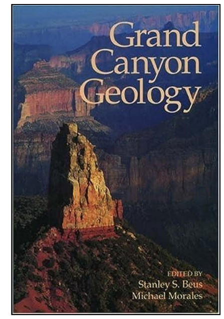
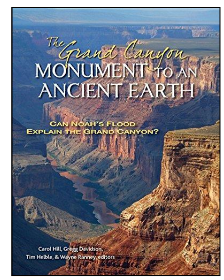


Figure 10. Google Earth image of the Grand Canyon Region showing major monoclinal folds. (Karlstrom and Timmons, 2012) Also shown are dots representing the location of sampling done by Dr. Snelling for his papers.



The Colorado Plateau has numerous monoclinal folds (step-like folds consisting of a zone of steeper dip within an otherwise horizontal or gently-dipping interval; **Figure 10**). Geologists have extensively studied (mapped, described, and modeled) these features.[8] While details about their origins and causes have been debated for years, many observations are clear and recognized by all investigators. The monoclinal folds are associated with deep-seated faults that began as normal faults in the Precambrian era. They were reactivated as compressional faults, associated with the Laramide orogeny in the late Mesozoic to early Cenozoic eras. This is the same overall mountain building event that formed the Rocky Mountains, regardless of how long ago it occurred. These faults cut through the Tonto Group and deformation associated with them includes the folds examined by Snelling.



Numerous cross-sections have been published of the folds in the Colorado Plateau. **Figure 11** shows a cross section of the East Kaibab Monocline (**EKM**) published in earlier articles by Snelling, which is similar to some of the early published cross sections of monoclines. This cross section, however, is highly simplified and does not accurately reflect the tight synclinal folds that Snelling studied or faulting through the Tapeats Sandstone. Until his 2023 article on the Carbon Canyon Fold, this was the only view that he presented. A more realistic cross section by Tindall[9] is shown in **Figure 12**. Tight synclinal folding of the Cambrian Tapeats Sandstone is illustrated on the downthrown side of the fault, the dip of bedding is very steep to

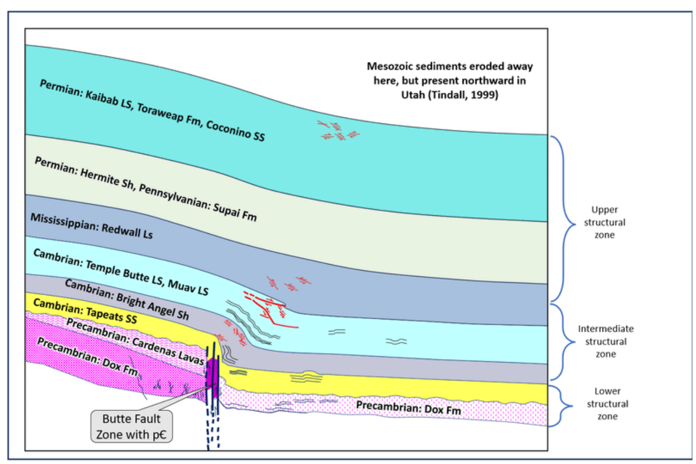


Figure 13. Composite cross section of the Palisades monocline (Reches, 1978). Reches chose to use a location where the folding was more evident in the Bright Angel Formation than in the Tapeats Sandstone. The Palisades monocline connects to and extends the EKM. (Note: the section has been flipped from the original publication to be consistent with the other cross-sections.)

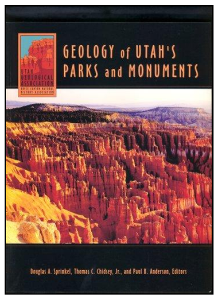
8. e.g., Ze'ev Reches and Matthews 1978; Ze'ev Reches and Johnson 1978; Huntoon 1990; Cooke et al. 1999; Tindall and Davis 1999; Tindall, Sarah E. 2000; Orofino, James Cory 2005; C. Hill 2016; Karlstrom and Timmons 2012; Tapp, Bryan and Wolgemuth, Ken 2016

9. Tindall 2000

https://doi.org/10.54739/k1y8 | **Peaceful Science**

overturned at the deepest levels adjacent to the fault and decreases upwards in the section, and the fault offsets the Proterozoic rocks and at least the base of the Cambrian section. Reches[10] published a composite cross section of the EKM (**Figure 13**) which is based on extensive work and it illustrates smaller-scale features from a number of locations along the monocline. The deformation is divided into lower, intermediate, and upper structural levels, summarized by Orofino (2005). In general, the amount of deformation decreases upwards. Lower levels include igneous intrusions and associated hydrothermal alteration, tighter folding and extensive fracturing and faulting, grading into gentler folds and fractures without displacement (i.e., joints).

Together Figures 12 and 13 provide a useful summary of the structural geometries of the monoclines in the Grand Canyon region and their associated subsidiary structures. Together with the map view, they allow us to understand when the folding developed. They demonstrate that the folding developed when the sediments were deeply buried and were much later exposed by extensive erosion.



Outcrop-scale and Microscopic-scale Observations

Now let's take a closer look at some of the actual smaller scaled folding associated with monoclinal folds in the Tonto Group. We will look at six examples (**Figures 14-20**). Four are from the Tapeats Sandstone: two from the EKM (**Figures 14 and 15**) and two from the Monument Monocline (**Figures 16 and 17**[11]). The two from the EKM are the Palisades Creek fold (**Figure 20**) and the Carbon Canyon fold; and the two from the Monument Monocline are the Monument fold and the Monument kink fold (see Figure 10 for locations). The Carbon Canyon fold and the Monument fold have also been studied by Snelling.[12] Two others are also studied by Snelling. They are the Whitmore Helipad Fold (**Figure 18**) in the BAS[13] and the Matkatamiba fold in the Muav Limestone (**Figure 19**).[14] Snelling has not provided cross-sections of any of the particular folds that he sampled, schematic or measured, and none are available in the literature. We will have to infer the setting for the sampled horizons based on photographs and a general understanding of the regional geology.

First, here are a few general observations. In four of these cases, the fold limbs dip steeply (in some cases the limbs are overturned), and the folds are relatively narrow, with bedding returning to sub-horizontal within a distance ranging from a few 10s of meters to a few 100s of meters. This tells us that the features are of the scale and type of the small folds illustrated in Figure 13. The examples in Figures 18 and 19 appear to be deformed similarly, but so far, we do not have views of them from far enough away to see the overall fold geometries. All of these are consistent with folding that developed as the monoclines deformed and the inherent space problems caused each of the local folds. We see such in our everyday experience, for instance as in the case mentioned earlier, cardboard boxes in an attic collapse. If they collapse in a confined space, the cardboard will tend to fold with some compressional features. What should we look for to tell if the folding took place as soft sediment deformation vs lithified rocks? We can examine both the overall geometries to see if they tell us that the rocks behaved as coherent rock or were they "soupy" soft sediments. As the figures show, the rocks today are faulted and quite

10. Reches 1978

11. Billingsley et al. 2019

12. Snelling 2009a; 2009b; 2012; 2021b; 2021b; 2023

13. Snelling 2021a; Snelling, Andrew A. 2021a

14. Snelling 2022; Snelling, Andrew A. 2022

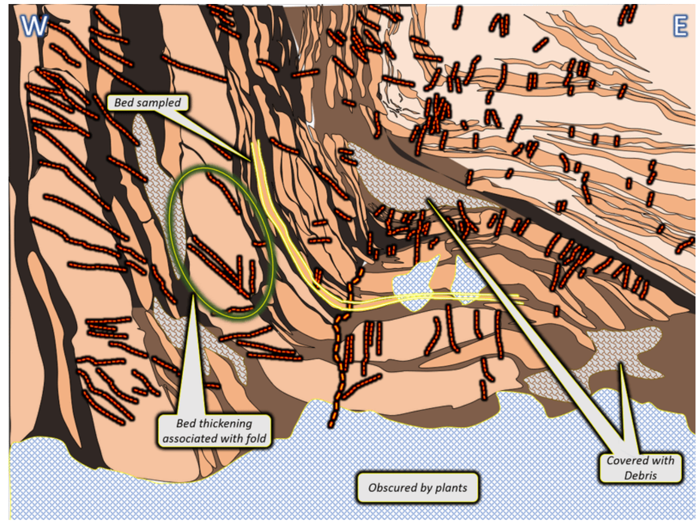


Figure 15. An interpretive line drawing of a Carbon Canyon photograph from Snellings, 2023 (p.103). Many macroscopic fractures are observed (traced in red), most of which appear to be related to the deformation. Fracture concentrations along the axial plane are present. Bed thickening and thinning associated with the deformation is present. One thickened interval is highlighted. Thickening along the axis in recessive beds appears to be present but debris makes it impossible to see details. As with Figure 14, the photo is reversed to match Figures 13 to 15. The bed outlined in yellow was sampled for Snelling's report (2021, 2021c)

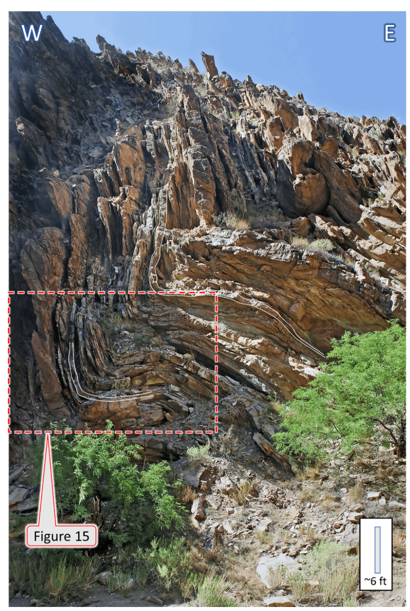


Figure 14. Carbon Canyon Fold. Recognize that this photo, oriented as the one in Snelling's article, is reversed to match the orientation of Figures 12 to 14. Notice the near vertical beds on the western side of the photo towards the upthrown block of the EKM. Beds outlined in white were sampled for Snelling's report (2021a, 2021b). The location of slide CCG-01, Figure 23, is labeled. Used with permission from

Ron Wolf

https://doi.org/10.54739/k1y8 | **Peaceful Science**

fractured. We can look for clues that tell us that the fractures were related to the folding vs. later joint development. We will look at evidence for the timing of the lithification using other clues.

It is worth noting that the published work is not complete enough to allow a thorough analysis. A complete structural analysis at the outcrop-scale requires multiple measured sections at different locations across the fold, abundant bedding orientation measurements to define the fold orientations and geometries, and measurements of the orientations of associated deformation features like fractures and faults. A complete structural analysis at the microscopic scale requires oriented samples from representative locations across the structure to document how microstructures vary as a function of structural position and lithology. Ideally one would use multiple samples from each lithology at multiple locations across the structure (even tracing individual beds across the structure if possible), as well as samples representing the various structural levels. Then one would examine oriented thin sections (in plane-polarized and cross-polarized light at a minimum) to document the types and orientations of microstructures. Typically, three mutually perpendicular thin sections are used that are oriented parallel to bedding, perpendicular to bedding and parallel to the fold axis, and perpendicular to bedding and perpendicular to the fold axis. Snelling (2023) shows that he is examining the slides that he has in appropriate ways, but there just are some limitations in the data that he collected. In the absence of this detailed data however, observations can still be gleaned from photographs, photomicrographs, and other publications. What we can do is use the data available to see what they tell us about the deformation.

If the folding develops in a continuum ranging between totally unlithified soft sediments to highly lithified hard rocks, can we tell if these rocks were more like the very "soupy" soft endmember, or did they behave like sediments that were already rock? As stated earlier, bedding-scale observations that can be used to distinguish between folding of lithified and unlithified sediments include: the presence or absence of fold-related fractures and faults, the presence or absence of flexural slip, and the nature of fold-related bedding thickness changes. The primary microscopic-scale deformation mechanism in unlithified sediments will be grain boundary sliding. In contrast, deformation mechanisms in lithified sediments potentially include: fracturing and faulting (of individual grains and across layers), internal distortion of grains, and dissolution and reprecipitation of minerals in response to stress (i.e., pressure solution). We will look to see indications of such in the photomicrographs published.

Do the outcrop observations indicate that the sediments were deformed as weak, unlithified rocks or as lithified rocks?

We will look at a series of questions to determine which model fits the data.

1. Do the folds have an overall "soupy" appearance or is their morphology more consistent with some degree of lithification?

Compare the soupy appearance of sediments in Figure 9 to the folding in the different Tonto folds. Two aspects that the Tonto folds have, particularly in the Monument fold (Figure 16) and the Kink Fold (Figure 17) are relatively planar limbs and fairly sharp hinges. Although perhaps not quite as distinct, the Matkatamiba Fold in the Moab Formation also has similar planar portions separated by fractures. Planar portions separated by kinks would not be found in sands folded by soft sediment deformation. These are clear indications that the sediments were behaving as coherent sets of rock beds with some degree of lithification.

2. Is faulting present associated with the folding?

First, it is agreed by all that lithified sediments deform commonly by faulting. While faulting is possible in softer sediments, it is much

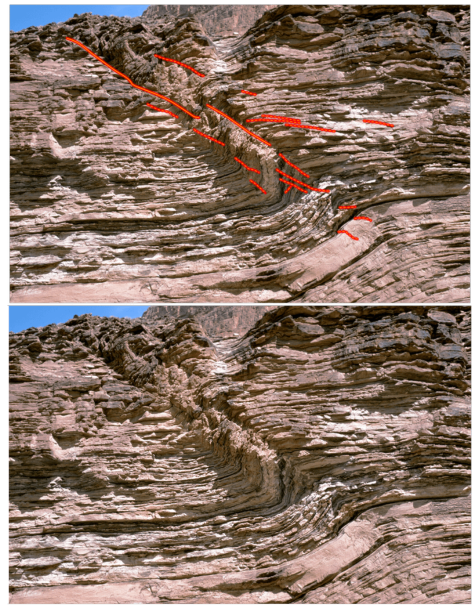


Figure 17. Kink Fold, Tapeats Sandstone, with and without interpretation of faults and fractures. Located near and part of deformation associated with Monument Monocline. Faults had only small amounts of displacement. (Photo by Billingsley, 2019)

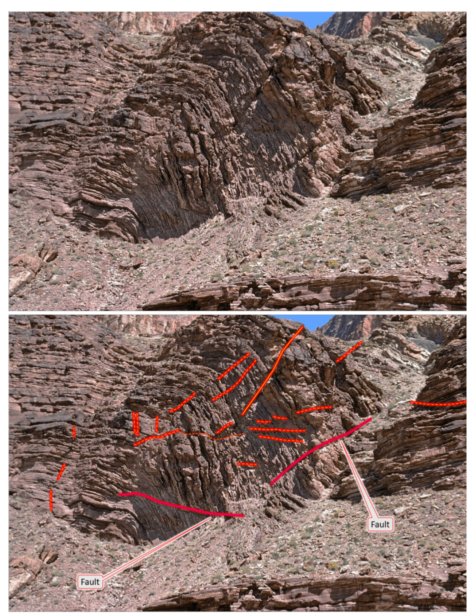


Figure 16. Monument fold, Tapeats Sandstone with and without interpreted faults and fractures that cross multiple beds. Fold sampled by Snelling and reported on his Tapeats reports (Snelling, 2021, 2021c) So far photos do not document clearly where much of the sampling was done. (Photo from: Billingsley, et al., 2019, CF04. View toward western part of Monument Fold in Tapeats Sandstone - ScienceBase-Catalog)

more common in lithified rocks. Is faulting common in the Tonto Group in deformation associated with the monoclines? Absolutely. And it is spatially associated with the folds. Faulting associated with the Laramide events reactivated previous older faults and cut through the overlying rocks as well. A well-documented example of this is the EKM: Palisades Creek Branch (Figure 20).[15] This location was selected because of the excellent 3D exposure of the monocline in a 1200-m-deep canyon showing strata from the Precambrian (Dox Fm) to the Permian (Kaibab Fm).[16] The presence of breccia in the fault

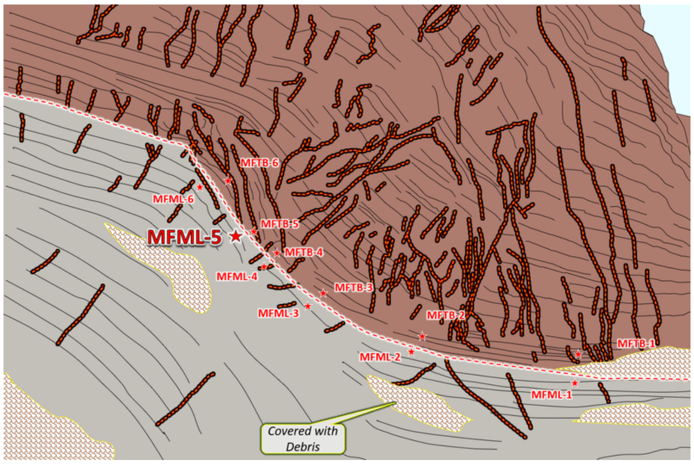


Figure 19. An interpretive line drawing of the Matkatamiba fold photograph from Snelling, 2022b (p.143). Here the fold includes fractures and faults (traced in red) in the Muav Limestone. Sampled beds are above and below the red dashed line that separates the Gateway Canyon Member of the Muav Formation below from the Havasu Member of the Muav above. The location of slide MFML-05, Figure 22, is labeled. Again, most of the macroscopic fracturing appears to be directly related to the deformation.

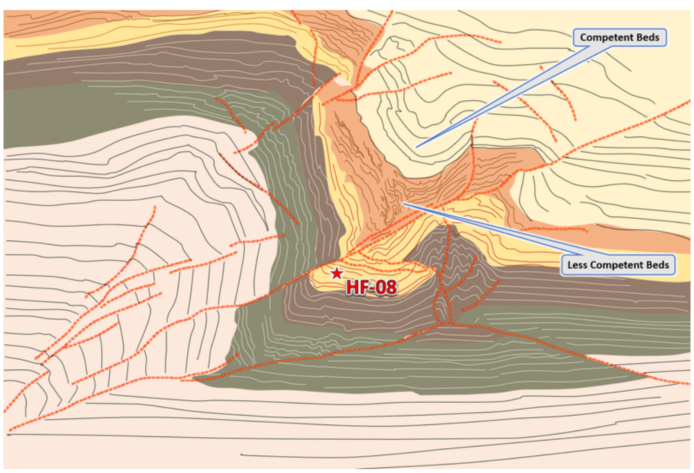


Figure 18. An interpretive line drawing of the Whitmore Helipad Fod photograph from Snelling, 2021b (p.307). Faults, traced in red, are clearly related to the formation of the fold. The fold morphology is consistent with that of a compressional fault-propagation-fold in the BAS. The folding is consistent with the folding and faulting of lithified sediment over long periods of time where the variations in the competency of the beds influence the smaller scale deformation. The location of slide HF-08, Figure 24, is labeled. The interpretation of stratigraphy could be made with more confidence if images were available showing more of the fold.

zone indicates that the faulted sediments were lithified during faulting, at least in Laramide time, if not also in the Precambrian. Faulting on smaller scales is also evident in Figures 14-19, although not as intense as that in the Palisades Creek Branch. This scale of faulting and brittle behavior is to be expected in the deformation of lithified sediments over long periods of time. If faulting were rare, it would support the soft sediment deformation model, but that is not the case here.

3. Is there significant fracture development associated with the folding?

All of the included folds show many fractures at the outcrop scale. Many of these have been interpreted on the photographs and interpretive line drawings. Reches and Matthews[17] reported from the Palisades Creek Branch that not only were the Precambrian rocks fractured, but the Cambrian and Mississippian rocks within the monocline are also intensely fractured.

We reported earlier that fractures that cut across layers or multiple grains do not form in unlithified sediments because of the lack of coherency in them. We can be confident that the degree of fracturing evident in these formed after they had been buried long enough to have become stone. The key question here is whether some or perhaps most fractures here developed associated with the deformation.

If the Tonto Group was once buried deeply and then uplifted and unroofed (exposed by the erosion of the rocks that originally overlaid them), this would have resulted in joints and fracturing. Late fractures associated with the unroofing are not necessarily expected to be aligned with the fold axis or fold limbs (their orientation is controlled by the regional stress field at the time of unroofing), but those that

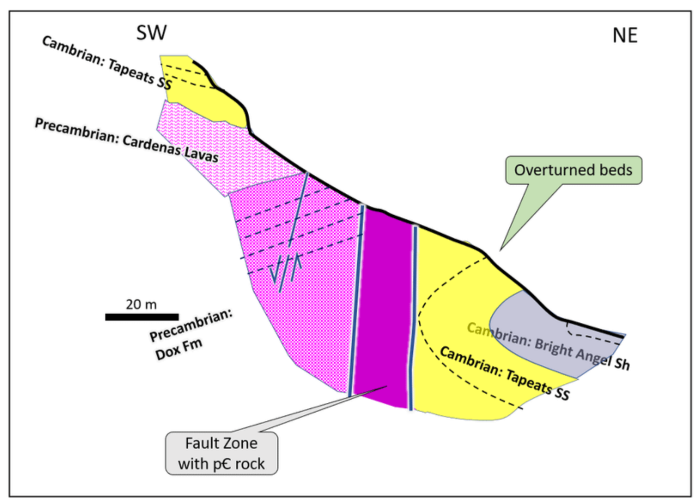


Figure 20. Approximately 120m (400 ft) long cross section across the Palisades Creek branch of the EKM (Reches, 1978, Figure 10). This shows a tight synclinal fold with overturned beds on the downthrown side of the fault zone. Located approximately 2 miles (3.4 km) southeast of the Carbon Canyon fold. (See Figure 10 for location). (Note: the section has been flipped from the original figure to match the orientation of the cross-sections shown previously)

15. Ze'ev Reches and Matthews 1978

16. The Palisades fault zone is a 5-60 m wide zone consisting of breccia (a rock consisting of large angular broken fragments), leached sandstone, and chemically altered basalt and sandstone. The presence of breccia in the fault zone indicates that the faulted sediments were lithified during faulting, at least in Laramide time, if not also in the Precambrian. Orofino (2005) used modeling to simulate the type of deformation and also documented the chemical alteration of the rocks in the fault zones by fluids, including the precipitation of new (i.e., non-sedimentary) minerals.

17. Reches and Matthews 1978

https://doi.org/10.54739/k1y8 | Peaceful Science

form during folding are expected to be geometrically related to the orientation of the fold. In addition, unroofing fractures are expected to be relatively uniformly distributed across the region, whereas syn-folding fractures are expected to be concentrated or more numerous within the folds than outside the folds. Fractures commonly form at a high angle to bedding due to the mechanical contrast between the layers, so this is expected in either case and therefore doesn't help us. Unfortunately, the required orientation data are not available. This data gap should be addressed in future studies.

What do we observe in the photographs? We see fractures in every case that seem to be related to the folds. In the Carbon Canyon fold, Figure 15, fractures are present approximately along the axial plane. Tapp and Wolgemuth[18] note that the orientation of the axial plane for this overall fold changed as the fold developed. They attribute this to changes that developed due to flexural slippage during the folding.[19] Perhaps the clearest examples of fractures associated with the folding are in the Kink Fold, Figure 17. The fractures in this small fold are definitively associated with the development of the fold. You should notice that no significant fractures are identified away from the fold.

4. Is evidence of flexural flow/slip?

As reported earlier, if the sediments were unlithified, then there would have been little difference in the competency between beds composed of sand, lime mud, silts, and muds. In this case, we would expect to find bedding thickness changes in all lithologies and little to no evidence of slip along bedding planes (i.e., flexural slip). If however, the beds were lithified, then one should expect to see thickness changes in the less competent units (e.g., muds) and evidence of flexural slip. We predicted that such evidence should include bedding parallel slickensides, bed thickening associated with the fold, including intense folding of less competent beds in the axis of folds.

We do find evidence of thickening of less competent beds associated with the folding. One example is highlighted in Figure 18. The sandstone bedding in the upper right is folded but not as intensely as the less competent beds beneath. The less competent units are intensely folded to fill the space created as the more rigid sandstones folded. This kind of bed thickening in the hinge zone is exactly the behavior one would expect from flexural flow deformation. Other examples will be highlighted from the Monument fold in our more detailed report.

Snelling does report that one surface of slickensides was noted near a sampled bed in the Carbon Canyon Fold.[20] Snelling[21] reports "*Thus, it is likely that slickensides on bedding plane surfaces in the Carbon Canyon fold are not prolific, yet this one occurrence is still significant*." It is not clear how extensively the workers looked for evidence of this or other evidence in the area. Such evidence might require digging in the recessive beds and have been difficult to complete. At the EKM, Tapp and Wolgemuth[22] show an example of evidence for flexural slip and Reches and Matthews (1978) reports the presence of slickensides on fold-related faults.

5. Is other evidence that the sediments were lithified, such as calcite twinning?

Fractures and faults are often filled with calcite. Twinning in calcite crystals reflects internal distortion of the crystal lattice due to stress and can be used to determine the orientations of the principal stresses that caused the distortion.[23] Calcite twinning would have developed only during the deformation of at least moderately lithified sediments. Reches and Matthews[24] documented abundant twinning of calcite grains in the Muav and Redwall Limestones at Palisades Creek. Calcite twins can be used to determine the shortening direction and Reches and Matthews[25] shows that these calcite twins indicated shortening perpendicular to the fold axis. Thus, the calcite twins are not only spatially associated with the fold, but they most likely formed at the same time as the folding. This supports the position that the units were lithified prior to deformation and is difficult to reconcile with a soft-sediment scenario.

Summary at outcrop scale

The outcrop observations all are consistent with folds that developed after the rocks were lithified.

1. The folds tend to have planar limbs and relatively sharp kinks (as opposed to a soupy appearance).
2. The more competent beds maintain thickness across the fold, whereas the less competent beds display thickening in the fold hinges.
3. Faulting and fracturing are associated with the folds.
4. There is evidence for flexural slip indicating layers with different competencies slid past each other during the folding.
5. Calcite crystals are twinned and indicate shortening perpendicular to the fold axes.

All these observations are difficult to reconcile with the FG model.

Do the microscopic observations of thin-sections indicate that the sediments were deformed as weak, unlithified rocks or as lithified rocks?

Next, we need to move in even closer, to the microscopic scale to see if observations there provide a different picture. Snelling collected 53 samples, sampling both folded and unfolded sediments in order to investigate deformation at this scale. Snelling[26] states that there is no obvious evidence of grain boundary sliding or rotation of grains and little to no evidence of any ductile deformation. If this is the case, then we have run out of deformation mechanisms and these rocks have not experienced any penetrative strain. (i.e., deformation that is pervasive throughout the rocks and not just localized in certain zones, like faults). If that is the case, then the beds should be planar and segmented by zones of localized deformation (i.e., faults), which is

18. Tapp and Wolgemuth 2016
19. Tapp, Bryan and Wolgemuth, Ken 2016, 125
20. Snelling, Andrew A. 2021b; Snelling 2023
21. Snelling 2023
22. Tapp and Wolgemuth 2016
23. Turner and Weiss 1963
24. Reches and Matthews 1978
25. Reches and Matthews 1978
26. Snelling 2023

clearly not the case. The fact that the beds are sinuously folded demonstrates that penetrative strains were involved, although the amount of penetrative strain required is rather small. His published photomicrographs show tightly packed grains and significant micro-fracturing, indicating the grains have been deformed under relatively low-grade deformational conditions. Here are some questions that help understand what the thin section slides show.

1. Is there evidence of metamorphism or high temperature/ pressure deformation?

Snelling's articles all make the point that the Tonto group shows no evidence of metamorphism or high-temperature/pressure (T/P) deformation. We agree. That is not the case for early Paleozoic rocks in many other places, but in this case, the thin sections confirm that these remain sedimentary rocks that have been changed from loose sediment to rock by burial and the precipitation of cements and were lithified and deformed at relatively low (T/P) conditions. Under these conditions, we do not expect extensive formation of sub-grains, deformation lamellae, kink bands or undulose extinction. Such features would reflect deformation at higher T/P conditions.

2. Are units cut by fractures or faults?

Most of the thin sections show evidence of fracturing. Some, such as the example in **Figure 21**, are intensely fractured at the scale of a few millimeters. The rock more resembles finely shattered porcelain than soft sands that were deformed. This particular sample was taken in a tighter synclinal portion of the Monument fold. Again, in the absence of detailed orientation and timing data it is not possible to definitively determine the timing of these deformation features relative to the timing of the monoclinal folding. Nonetheless, all the evidence at this fold is consistent with folding of previously lithified sediments.

Another example from the Matkatamiba Fold shows multiple generations of fractures (**Figure 22**). In this case we see rock that was fractured (possibly including pressure dissolution), later the fractures filled with iron oxides and then the rock fractured again, and the later fractures later filled with calcite.

3. Is there evidence of internal destruction of grains?

We said that when soft sediments are folded, the grains are able to shift and thus are not fractured, deforming by grain boundary sliding. The more strongly lithified the rock was prior to folding the less grain boundary sliding would have been possible and the more fracturing of grains and cement occurs. We see abundant evidence of grains fractured in Figure 21. **Figure 23** from the Carbon Canyon Fold also shows evidence of fractures extending through original grains. In some cases, the same fractures cut across multiple grains. It appears that the fractures include fragments of shattered grains and cut through cement, but to be sure of this, one would need to examine the actual slides. The degree to which fractures cut grains is also particularly difficult to observe in fine grained rocks. Even so, the slide shown in **Figure 24** shows dark rounded areas that were cemented before being cut by fractures with small amounts of offset. Snelling suggests that these could have been detrital carbonate clasts but cross-bedding appears to extend through them, suggesting that these are concretions.[27] In either case, these features would

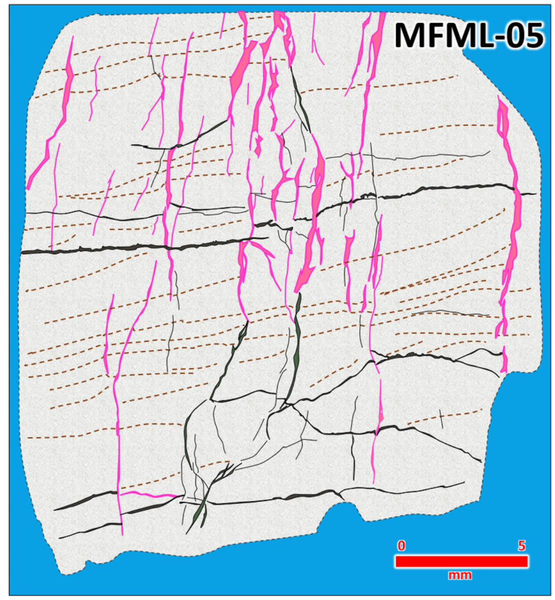


Figure 22. Siltstone from the Muav Limestone (52% quartz and K-feldspar) cut by fractures, primarily horizontal and vertical. The horizontal fractures formed first and often filled with iron-oxide material. Vertical fractures are mostly filled with calcite (stained pink) and offset the horizontal fractures. This is an interpretive line drawing of a photograph in the Muav Formation Supplement (Snelling, 2022a: Appendix E – Locations and Petrographic Descriptions of Muav Formation Samples).

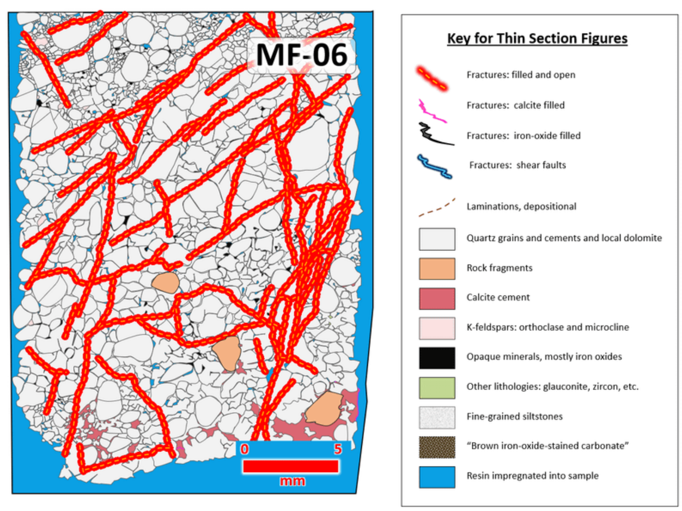


Figure 21. Interpretive line drawing of an example from the Monument fold of a heavily fractured coarse sandsto1e. Many grains are fractured. Some fractures show offset, but others do not. This is an interpretation of a photograph in the Tapeats Supplement (Snelling, 2021: Appendix D – Locations and Petrographic Descriptions of Tapeats Sandstone Samples). Note that the blue material in this and following slides is resin impregnated during slide preparation showing open pores and fractures. Some fractures may have been induced during impregnation, but most are original. The light gray quartz in this and following slides represents original grains and cement as it is in many cases difficult to recognize in the difference, particularly for the smaller grains. This makes it difficult to demonstrate the relationship between the fractures and the cement, though the photograph suggests that the cementation took place prior to the fracturing. The sample location is near a synclinal axis with small faults nearby, suggesting that the factures on the slide were related to the deformation.

27. A concretion is a hardened body that formed in a sedimentary rock when mineral cement concentrated in a local area. They are often round or ovoid, though many shapes are formed. In many cases, they weather out of softer, less cemented rocks at the surface.

https://doi.org/10.54739/k1y8 | **Peaceful Science**

have formed early, perhaps soon after deposition and hardened as iron oxides in solution concentrated in local areas. Brittle fractures through such features would be difficult to reconcile with soft sediment deformation.

4. Are more heavily deformed areas more heavily fractured?

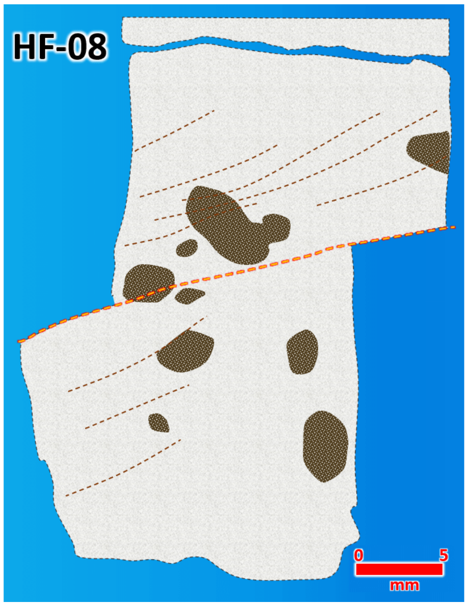


Figure 24. Example from the BAS in the Whitmore Helipad Fold. This shows apparent horizontal displacement of approximately 5mm (edges of the thin section are aligned in the original photo; top of the thin section has been displaced to the right along the red fault). Dark areas are described as "brown iron-oxide-stained carbonate (which could be detrital carbonate clasts given their rounded shape and reasonably defined edges)". This figure is an interpretive line drawing of a portion of a photograph in the Bright Angel Supplement (Snelling, 2021a: Appendix D – Locations and Petrographic Descriptions of Bright Angel Formation Samples). No attempt was made to digitize the fine-grained, cemented sandstone grains.

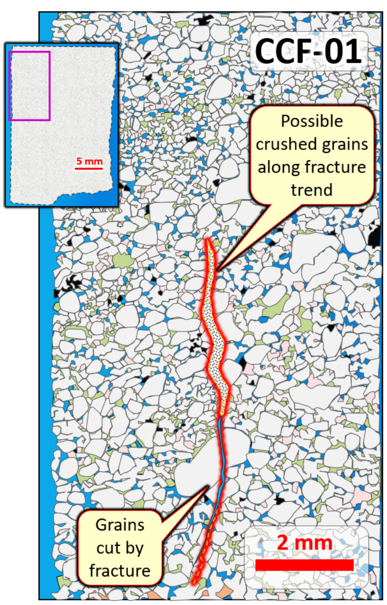


Figure 23. Example from the Carbon Canyon fold of a fracture cutting through the quartz grains. This is an interpretive line drawing of a portion of a photograph in the Tapeats Supplement (Snelling, 2021: Appendix D – Locations and Petrographic Descriptions of Tapeats Sandstone Samples). The slide location is shown in Figure 16.

Snelling also collected samples away from the folds to compare these relatively undeformed rocks with the rocks from the folds. These less deformed samples are fractured, but not as extensively. We noted earlier that if the fractures are concentrated or more numerous within the folds than outside the folds, and if the orientations of the fractures are geometrically related to the orientation of the fold (e.g., strike parallel and perpendicular to the fold axis), then it is highly likely that the fractures formed during folding. While our information is incomplete, it is significant that the slides with the highest degree of fracturing are all in highly deformed parts of the folds. These include those in Figures 21 and 22. Possible concretions such as in Figure 24, showing horizontal offset, are from near the fold axis, as are slides HF-04 and HF-05. While the dataset has its limitations, the data available indicate that much of the fracturing of lithified rock was associated with the folding.

5. Is there evidence of cataclasis and shearing?

One final piece of evidence will be included here. We said that fractures with shear typically exhibit cataclasis, the crushing of the rock typified by the fracturing of grains, grain-size reduction, and compaction. Such might often be difficult to sample as the bands might well be eroded out or crumbly.

However, some samples, such as from the nose of the Monument fold, show good evidence of shear and cataclasis as shown in Figure 25. Shear in soft sediment would not have crushed grains such as are evident in the figure.

Summary at microscopic scale

The observations of the thin-section photos provided in Snelling's supplements are exactly what one would expect from moderate

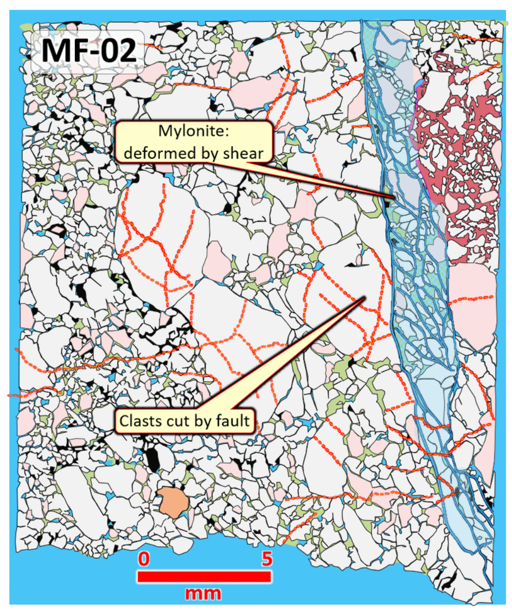


Figure 25. Example from the Monument fold showing deformed zone with that resulted from tectonic shearing. Many fractures are present (traced in red). Grains are also fractured outside of the sheared zone and the shear faulting through both quartz and K-feldspar clasts. This is an interpretive line drawing of a portion of a photograph in the Tapeats Supplement (Snelling, 2021: Appendix D – Locations and Petrographic Descriptions of Tapeats Sandstone Samples). The sample was taken in a zone between two small faults as illustrated in the Tapeats Supplement and this shearing was probably associated with those faults.

https://doi.org/10.54739/k1y8 | **Peaceful Science**

deformation of lithified sediments at relatively low temperature and pressure conditions over a long period of time. These observations are inconsistent with soft sediment deformation.

Implications of observations of deformation

Taken together, the observations of the fold morphologies, the subsidiary fractures and faults, and the microscopic-scale features at the four locations all strongly suggest that the Paleozoic sediments, including the Tonto Group were lithified at the time of folding. The fold morphologies, the presence of fold-related subsidiary faults, fractures, and folds, and the micro-fracturing/faulting and calcite twinning are all inconsistent with soft sediment deformation. If correct, this conclusion poses a major challenge to the YEC model. To either challenge or strengthen this conclusion, a thorough structural analysis of additional orientation and distribution data on the folds, subsidiary outcrop-scale structures, and microscopic-scale deformation is required.

But this is not the only challenge to the YEC claim that the monoclinal folds in the Grand Canyon region formed by soft-sediment deformation. Other sedimentary units, both older and younger than the Tonto Group, appear to have been lithified during Laramide folding. The documented Laramide-age folding of the Precambrian sediments[28] is also inconsistent with the YEC model. In order for this folding to have occurred at the strain rates required by the YEC model, the Precambrian sediments would also have had to been unlithified. But the fact that these sediments form erosional paleo-topographic highs under the Great Unconformity and have been brecciated in the faults that underlie and created the monoclines, clearly demonstrate that these sediments were lithified by Laramide time. In addition, further north along the EKM in Utah, Cooke et al.[29] documented the occurrence of joints related to fold curvature and flexural slip ("dune boundary slip") in the Navajo Formation. This indicates that the Jurassic Navajo Formation, which is much higher in the section, was lithified at the time of folding. Add to this the work by Tindall and Davis[30] who studied the structural geology of the EKM along a ~50 km stretch from the AZ-UT border northward. They document the presence of a suite of fold-related brittle faults exposed in all stratigraphic intervals from Proterozoic through Cretaceous, indicating that the entire stratigraphic column up to at least the Cretaceous was lithified at the time of folding. Even more problematic for the FG model, is the fact that the faults that are related to the folds cut deeper into the Precambrian rocks. Soft sediment deformation related to a catastrophic flood should be restricted to the overlying sediments and should not cause deeply seated deformation.

But even this is only the proverbial tip-of-the-iceberg of the challenges to the YEC cataclysmic flood model posed by deformation of rocks categorized as syn- or post-flood in the flood model. The flood model requires all folding of rocks everywhere in the world that occurred during the flood or post-flood interval to have happened quickly, including folding of igneous and metamorphic rocks. Paleozoic, Mesozoic, and Cenozoic rocks of many types have been deformed in many places around the world, and in many cases, it is well documented that the rocks were lithified at the time of deformation.

Furthermore, there are many cases where Phanerozoic rocks have been metamorphosed as well as deformed, and it is difficult for the FG to account for both. In the more detailed report, we cite particular evidence from southeastern Arizona where late Mesozoic rocks are metamorphosed and highly folded. This means that, in Snelling's age model, in the last stages of Noah's flood, rocks were deeply buried, hardened, metamorphosed, and highly folded. Later they were exhumed to the Earth's surface. We also cite an example from the Taiwan fold-and-thrust belt. Tillman and Byrne[31] (The same Tillman that is the primary author of the deformation section of this paper) studied the deformation of Eocene and Oligocene sediments in the Slate Belt. As such, in Snelling's age model, this would have been deposited about 4000 years ago over a period of at most a few hundred years. These authors document that the sediments were lithified and metamorphosed as "lower greenschist facies" at high temperatures, now demonstrated to have ranged from ~300-500 °C.[32] This deposition, burial, metamorphism, and erosion had to take place at incredible rates in any YEC model.

In summary, the morphologies of the monoclinal folds in the Tonto Group sedimentary rocks in the Grand Canyon, the orientations and distributions of subsidiary faults and folds, and the observations of outcrop-scale and grain-scale deformation mechanisms suggest that the sediments were lithified (i.e., they were not soft sediments) at the time of folding. But the YEC catastrophic flood model not only has to explain the monoclinal folding in the Grand Canyon, but also all deformation of rocks categorized as syn- or post-flood around the world. The Catalina MCC and the Taiwan fold-and-thrust belt are just two examples that exhibit deformation processes that are inconsistent with the YEC models and complex geologic histories that are exceedingly difficult for the YEC FG to explain. In contrast, all these observations can be consistently and coherently explained using accepted geologic principles acting over deep geologic time.

Tonto Diagenesis

The Tonto Group was deposited as loose sands, muds and lime muds. Today they are hardened sandstones, mudstones and limestones. The processes that turned them into lithified rocks are collectively known as diagenesis. Most geologists consider the Cambrian rocks here to have become deeply buried over the course of ~425 million years. The folding then took place over the course of ~20 million years. Such timing allows plenty of opportunity for diagenesis to harden the rocks. For any FG model to work, the rocks had to have been soft and unlithified during the deformation. They also need to account for when and how the lithification (or diagenesis) took place. Two key diagenetic effects that are recognized are quartz and calcite cementation. Overall, it is not often easy for us to evaluate the timing of quartz cementation relative to the fracturing on the available thin section photographs. Slides like MF-03 and MF-04, however, indicate that calcite cement is cut by fracturing. It also appears that quartz cement was cut by fractures in slides such as MF-02. This indicates that significant cementation took place prior to the fracturing.

28. Huntoon 1990

29. Cooke et al. 1999

30. Tindall and Davis 1999

31. Tillman and Byrne 1995

32. Beyssac et al. 2007

Because the fractures are both spatially and geometrically associated with the folds, it is likely that the cementation predates the folding.

Figure 1 shows the time available in Snelling's model at a scale that includes all of geologic history. **Figure 26** expands the late Cretaceous to Recent, in order to help show how events had to work in the two leading flood geology models. In Snelling's model, the Laramide folding in the Grand Canyon, beginning in the late Cretaceous period, and continuing into the Paleocene epoch, would have been late in the flood and continued into the early post-flood period. As illustrated in Figure 26, that period would seem to have been at most a few years long in Snelling's model, given that all of the Paleocene, Eocene, Oligocene, Miocene and Pliocene and at least part of the Pleistocene would have lasted just 350 - 450 years. Notice that the folding would have been in the middle of the flood in the ICR model proposed by Dr. Clarey, and therefore would have occurred in a matter of days. This leaves a very short time for diagenesis to have occurred.

Additional complications for the FG model result from the fact that much rock had to be eroded away in order to expose the folds in the Grand Canyon today. Do they believe that the canyon was carved while the sediments were unlithified as well? That would present even more problems. Here are some observations that would need to be reconciled for any FG model to be viable:

1. Originally, the sands and muds would have been highly porous and uncemented.
2. The Tonto group is now well lithified over a broad area of hundreds of square miles.[33] The process of lithification had to work over this entire area.
3. Today the sandstones are dominantly cemented by quartz, though locally, calcite, dolomite and iron oxide cements are found. The limestones of the Muav Limestone are also well lithified.

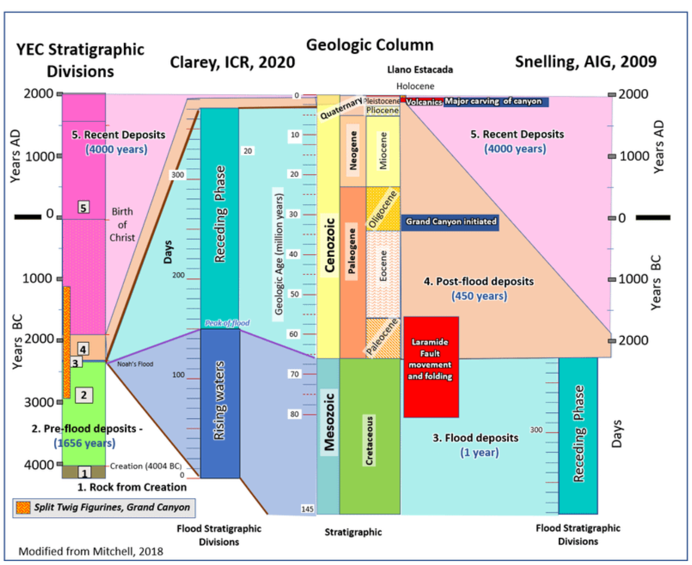


Figure 26. Expansion of the Cenozoic and late Mesozoic Eras from Figure 1. The Laramide orogeny is labeled, along with accepted dates for formation of the Grand Canyon and igneous events.

33. Uphoff, 1997; Irwin, et al., 1971

4. The Colorado River carved the present-day Grand Canyon through the hard lithified strata. a. If the sands were unlithified when the canyon was carved, the canyon walls would have collapsed very quickly and never developed the steep canyon walls that we observe today. b. If the sands were unlithified when the canyon was carved and then somehow quickly hardened afterward, sands in well penetrations away from the canyon would have been different, presumably remaining unlithified or lithified by some different process.
5. Many lava flows flowed over the edge of the canyon and down the walls. Several lava dams formed, temporarily blocking the river, and created ancient lakes in the canyon. These have been dated to the Miocene to Pleistocene era.
6. About 4000 years ago, early Native Americans began living in caves in the canyon, telling us the canyon was present at that time in essentially the same form as we see it today (**Figure 27**).[34]

Together these observations dramatically constrain the time available in the FG models for the regionally extensive diagenesis to occur. For Snelling's model, diagenesis would have to occur within a few hundred years. For Carey's model, it would have to happen in a matter of days.

FG explanations

Dr. Snelling does not propose that the sands were unlithified when the Grand Canyon was carved, despite the fact that his model leaves very little time for this erosion. He asserts two key points:

1. Diagenesis can take place very quickly.
2. Erosion of hardened rocks can take place very rapidly.

Given the timeframe his Biblical interpretation constrains him to, he could hardly argue otherwise. Here is one comment on the first assertion.

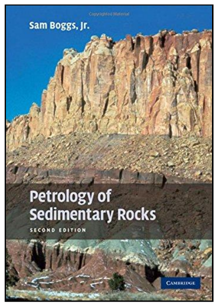
> Nevertheless, all sedimentary strata do become lithified, hard, and brittle, because under normal conditions sediments lithify relatively

Figure 27. Split Twig figurine from the Grand Canyon. Such figures, dated from 4100–3530 BP as shown on the left side of Figure 26. (Emslie and Coats, 2013).

34. Emslie and Coats 2013

> quickly, often in a matter of years, but at most, perhaps hundreds of years. Given ideal conditions, lithification can happen within days.[35]

This is a claim that few if any petrologists would support. There are a few types of lithification that can take place quickly, but this claim does not fit what we typically observe in sedimentary rocks. How does he propose that such rapid rates occurred? Snelling basically claims that hypothetically, Noah's flood had lots of chemicals, diagenesis would have acted at exceptionally rapid rates. This is a hypothesis that is consistent with his interpretation, but it lacks supporting data. Remember that the cementation to be explained took place over an area of hundreds of square miles, just considering the Tapeats.



The dominant process of lithification in the clastic beds of the Tonto group was silica cementation, in the form of quartz overgrowths. The thin section photos that are included in Snelling's papers show significant amounts of silica cementation and apparent modification of grains as they were compacted. Silica cementation in natural settings takes place very slowly. As water moved through the pore spaces carrying silica, some was precipitated. This had to take place over and over again to cement the rock.[36] How long did this take? We understand controls that affect the rate. Temperature is one major control on the rate of diagenesis of all forms, including quartz overgrowths. Were the floodwaters boiling? Walderhaug[37] noted:

> On the other hand, for the sandstones where the present temperature is below 100°C, it must also be kept in mind that at these low temperatures, it may take several million years to precipitate enough quartz cement to close a fluid inclusion large enough to permit measurement of homogenization temperature.

As the Tonto rocks were buried, they did heat up, but we have already noted that they were not subject to extreme heat or pressure. Quartz cementation may well have taken place when the rocks were heated to 80-150°C. but these temperatures will not allow noticeable cementation in a few hundred years.

Different processes acted in the limestones and siltstones of the Muav Formation. For instance, the Muav slide descriptions (Snelling, Andrew A. 2022) show that the following processes occurred in this order: 1. silica cementation; 2. calcite cementation; 3. dolomitization; 4. calcite-filling of fractures; 5. iron oxide deposition along fractures; 6. additional calcite filling of fractures. While we may not be able to document the time involved in each stage, the chemical processes did not take place all at once, but acted in a distinct order. Other events are also evident, such as the alteration of feldspars and micas. Such events were not localized to the canyon walls, but occurred over broad regions. These imply time frames of millions of years.

35. Snelling 2009a, 598

36. Boggs, Sam Jr 2009

37. Walderhaug 1994

Erosion

Snelling's next assertion is that the erosion of hardened rocks can take place very rapidly. Recognizing that the rocks in the canyons of the Colorado Plateau were lithified when the rivers cut through them, given his timeline, he must consider the erosion involved to have been catastrophic. In his 2014 article, "When and How Did the Grand Canyon Form?', Snelling points out "three undisputed observations". They are: 1. "Enormous scale of erosion". This is quite true. 2. "The Grand Canyon Was Cut Through the Plateau." No problem. 3. "Uplift of This Plateau Occurred Before Erosion of the Grand Canyon". Here we would need to modify this observation. Certainly, much erosion took place after the uplift. However, much erosion in the Grand Canyon and in all of the canyons of the Colorado Plateau took place *as* the plateau was being uplifted.[38]

A spectacular example documenting this is the Goosenecks of the San Juan River (Figure 28). In this location, the river valley has a very anomalous form. To recognize why this is anomalous, think about how rivers in normal areas develop. In the upper parts of rivers, they tend to cut down through rock with patterns that branch like a tree. In the middle course of the river, the gradient is gentle. High volumes of water and energy make the river migrate laterally in loops known as meanders. The Goosenecks are anomalous because the river has the meandering form of a river flowing on a low relief surface, but it downcut 1000 feet, down into Paleozoic limestones and sandstones, as the Colorado Plateau was gradually uplifted. In other words, the meanders were already present when the river was on relatively flat ground and then cut down into the bedrock as the plateau was uplifted. Such "entrenched" meanders show that the uplift had to be gradual in order to preserve the meandering form. This contradicts the FG models.

Figure 28. Goosenecks State Park, Mexican Hat, Utah. The San Juan River cut down through Paleozoic rocks as the Colorado Plateau was uplifted. This preserved the original river path that formed as the river meandered across an earlier low relief surface. The uplift re-energized the river, causing it to begin to downcut, but the uplift could not have been rpid or the meanders would not have been preserved.

38. Heitmann et al. 2021; C. A. Hill and Ranney 2008; Karlstrom et al. 2022; Roberts et al. 2012

https://doi.org/10.54739/k1y8 | **Peaceful Science**

Conclusions

YEC authors such as Dr. Snelling base their interpretation of geology on their interpretation of Genesis, despite the fact that the Bible does not say how old the Earth is or what the geologic results of Noah's flood were. YEC authors maintain that the scientific data support their interpretations and this article tests that claim. The YEC reading of Genesis drives them to force much of the geologic record into this one-year-long global catastrophe. The spectacular exposures of the Grand Canyon have drawn much attention from YEC geologists. They have made a number of efforts to demonstrate that FG can provide options for the Grand Canyon rock record that are viable, if not better than old Earth interpretations accepted by most geologists. Snelling received permission and sampled the Tapeats Sandstone, BAS, and Muav Formation, hoping to demonstrate that consensus geologic models are not supported by the details in the sediments. As documented here, we have not found this to be the case. Although we expect that Dr. Snelling will be presenting his work further, particularly on the structural aspects of these units, his conclusions are not expected to change.

We began by pointing out that FG explanations for the Tonto Group, at a minimum, need to answer four questions, rephrased here.

1. Could the sediments have been deposited in a few days?
2. Could the sediments have been deposited by catastrophic flood processes?
3. Could the rocks have been folded by rapid soft sediment deformation over days?
4. Is there scientific support for the deposits having been deposited less than 10,000 years ago?

We presented evidence that makes each of these difficult or impossible to answer with a yes or maybe. We actually summarized this at the beginning with a table with stoplight signals that explain our findings. In some cases, Snelling recognizes the same evidence that we do, but believes that there are alternative explanations that can be applied to the Tonto instances. We have pointed out that if this group were deposited by a global catastrophic event, encompassing most of the geologic record, then it must be able to explain other global examples as well. Many of these include other details that make them even more difficult to reconcile with YEC models. This report has not tried to answer every line of reasoning presented in the reviewed papers. Most of the characteristics that were not addressed, such as radiometric dating, glauconite pellets, rates of deposition of shales, detailed review of catastrophic tectonics, etc. also point to deep time, but this report is already long enough. Although YEC proponents have made sincere efforts to present a scientifically plausible case that the entire geologic history (post the Great Unconformity) of the Grand Canyon occurred in less than 10,000 years, their models remain fraught with problems. The data strongly indicates that the Grand Canyon, and the earth in general, is much older than they propose.

Acknowledgements

We are grateful to those who have contributed and encouraged this paper. Particularly we appreciate suggestions and edits from Dr. Lorence Collins and Dr. Ken Wolgemuth.

References

"10 Best Evidences From Science That Confirm a Young Earth: #2 Bent Rock Layers." 2012. *Answers in Genesis.* 2012.

Beyssac, Olivier, Martine Simoes, Jean Philippe Avouac, Kenneth A. Farley, Yue-Gau Chen, Yu-Chang Chan, and Bruno Goffé. 2007. "Late Cenozoic Metamorphic Evolution and Exhumation of Taiwan." *Tectonics* 26 (6). [doi:10.1029/2006TC002064][https://doi.org/10.1029/2006TC002064]

Billingsley, George H, Gregory Goodwin, Sarah E Nagorsen, Monica E Erdman, and Jason T Sherba. 2019. "Geologic and Related Photographs of the Grand Canyon Region (1967-2010)." U.S. Geological Survey. doi:10.5066/F7WS8SHW

Boggs, Sam Jr. 2009. *Petrology of Sedimentary Rocks.* 2nd edition. Cambridge; New York: Cambridge University Press.

Burg, Jean-Pierre. 2018. "Script to Structural Geology." ETH Zurich's Research Collection, 177–206. doi:10.3929/ETHZ-B-000279493

Cooke, Michele, Pauline Mollema, David Pollard, and Ayet Şamil Aydın. 1999. "Interlayer Slip and Joint Localization in the East Kaibab Monocline, Utah: Field Evidence and Results from Numerical Modelling." *Geological Society, London, Special Publications* 169 (January): 23–49. doi:10.1144/GSL.SP.2000.169.01.03

Emslie, Steven D., and Larry Coats. 2013. "Late Holocene Climate Change and the Origin of the 'Figurine Complex' In Grand Canyon, Arizona." *Journal of Ethnobiology* 33 (2): 170–79. doi:10.2993/0278-0771-33.2.170

Fossen, Haakon. 2010. *Structural Geology.* Cambridge UP, Hardcover.

Heitmann, Emma O., Ethan G. Hyland, Philip Schoettle-Greene, Cassandra A. P. Brigham, and Katharine W. Huntington. 2021. "Rise of the Colorado Plateau: A Synthesis of Paleoelevation Constraints From the Region and a Path Forward Using Temperature-Based Elevation Proxies." *Frontiers in Earth Science* 9. doi:10.3389/feart.2021.648605

Hill, C.A., and Wayne Ranney. 2008. "A Proposed Laramide Proto-Grand Canyon." *Geomorphology* 102 (December): 482–95. doi:10.1016/j.geomorph.2008.05.039

Hill, Carol. 2016. "The Grand Canyon, Monument to an Ancient Earth: Can Noah's Flood Explain the Grand Canyon?" *Perspectives on Science and Christian Faith* 68 (4): 268–71.

Huntoon, Peter W. 1990. "Phanerozoic Structural Geology of the Grand Canyon." In *Grand Canyon Geology.* Oxford University Press.

Karlstrom, Karl E., and J. Michael Timmons. 2012. "Faulting and Uplift in the Grand Canyon Region." *Grand Canyon Geology: Two Billion Years of Earth's History* Geological Society of America Special Paper 489: 93.

Karlstrom, Karl E., Justin Wilgus, Jacob O. Thacker, Brandon Schmandt, David Coblentz, and Micael Albonico. 2022. "Tectonics of the Colorado Plateau and Its Margins." *Annual Review of Earth and Planetary Sciences* 50 (1): 295–322. doi:10.1146/annurev-earth-032320-111432

Orofino, James Cory. 2005. "Structural Fabric of the Palisades Monocline: A Study of Positive Inversion, Grand Canyon, Arizona." MS Thesis, Texas A&M University.

Reches, Ze'ev, and Arvid M. Johnson. 1978. "Development of Monoclines: Part II. Theoretical Analysis of Monoclines." In *Laramide Folding Associated with Basement Block Faulting in the Western United States*, edited by Vincent Matthews III, 151:0. Geological Society of America. doi:10.1130/MEM151-p273

Reches, Ze'ev, and Vincent Matthews III. 1978. "Development of Monoclines: Part I. Structure of the Palisades Creek Branch of the East Kaibab Monocline, Grand Canyon, Arizona." In *Laramide Folding*

Associated with Basement Block Faulting in the Western United States, 151:0. Geological Society of America. doi:10.1130/MEM151-p235

Roberts, G. G., N. J. White, G. L. Martin-Brandis, and A. G. Crosby. 2012. "An Uplift History of the Colorado Plateau and Its Surroundings from Inverse Modeling of Longitudinal River Profiles." *Tectonics* 31 (4). doi:10.1029/2012TC003107

Snelling, Andrew A. 2009a. *Earth's Catastrophic Past.* Institute for Creation Research.

Snelling, Andrew A. 2009b. "Flood Evidence Number Six: Rock Layers Folded Not Fractured." *Answers Research Journal*.

Snelling, Andrew A. 2021a. "Bright Angel Supplement." Answers in Genesis.

Snelling, Andrew A. 2021b. "Tapeats Sandstone Supplement." Answers in Genesis.

Snelling, Andrew. 2021a. "The Petrology of the Bright Angel Formation, Tonto Group, Grand Canyon, Arizona." *Answers Research Journal* 14, 303–415.

Snelling, Andrew. 2021b. "The Petrology of the Tapeats Sandstone, Tonto Group, Grand Canyon, Arizona." *Answers Research Journal* 14, 159–254.

Snelling, Andrew A. 2022. "Muav Supplement." Answers in Genesis.

Snelling, Andrew. 2022. "The Petrology of the Muav Formation, Tonto Group, Grand Canyon, Arizona." *Answers Research Journal* 15, 139–262.

Snelling, Andrew. 2023. "The Carbon Canyon Fold, Eastern Grand Canyon, Arizona." *Answers Research Journal* 16, 1-124.

Snelling, Andrew A. n.d. "The Fight for 53 Rocks." Answers in Genesis. Accessed October 6, 2023.

Tapp, Bryan and Wolgemuth, Ken. 2016. "Broken and Bent Rock, Fractures, Faults, and Folds." In *The Grand Canyon, Monument to an Ancient Earth; Can Noah's Flood Explain the Grand Canyon?*, edited by Hill, Carol A, Davidson, Gregg, Helbe, Tim, and Ranney, Wayne, 116–27. Solid Rock Lectures and Kregel Publications.

Tillman, Kennen S., and Timothy B. Byrne. 1995. "Kinematic Analysis of the Taiwan Slate Belt." *Tectonics* 14 (2): 322. doi:10.1029/94TC02451

Tindall, Sarah E. 2000. ["The Cockscomb Segment of the East Kaibab Monocline: Taking the Structural Plunge."] In *Geology of Utah's Parks and Monuments: Utah Geological Association Publication* 28, edited by D. A. Sprinkel, T. C. Chidsey Jr, and P. B. Anderson.

Tindall, Sarah E., and G. H. Davis. 1999. "Monocline Development by Oblique-Slip Fault-Propagation Folding: The East Kaibab Monocline, Colorado Plateau, Utah." *Journal of Structural Geology* 21 (10): 1303–20. doi:10.1016/S0191-8141(99)00089-9

Turner, Francis J., and Lionel Edward Weiss. 1963. *Structural Analysis of Metamorphic Tectonites.* McGraw-Hill.

Walderhaug, O. 1994. "Precipitation Rates for Quartz Cement in Sandstones Determined by Fluid-Inclusion Microthermometry and Temperature-History Modeling." *Journal of Sedimentary Research* 64 (2a): 324. doi:10.2110/jsr.64.324

Acronyms Used

Acronym	Full Term
AIG	Answers in Genesis
BAS	Bright Angel Shale
EKM	East Kaibab Monocline
FG	Flood geology or flood geologist
GU	Great Unconformity
HCS	Hummocky Cross-stratification
ICR	Institute for Creation Research
YEC	Young Earth Creationism or Young Earth Creationist

Links

https://www.flickr.com/photos/rwolf/51077567833/in/album-72157630005144558

https://www.sciencebase.gov/catalog/item/5c75a46be4b0fe48cb4a5071

https://answersresearchjournal.org/petrology-tapeats-sandstone-tonto-group

https://answersresearchjournal.org/petrology-bright-angel-tonto-group

https://answersresearchjournal.org/geology/petrology-muav-formation-tonto-group

https://answersingenesis.org/geology/rock-layers/2-bent-rock-layers

https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2006TC002064

https://www.sciencebase.gov/catalog/item/5a9751d5e4b06990606c5197

https://doi.org/10.5066/F7WS8SHW

https://amazon.com/dp/0521897165/

https://www.research-collection.ethz.ch/handle/20.500.11850/279493

https://doi.org/10.3929/ETHZ-B-000279493

https://www.lyellcollection.org/doi/abs/10.1144/GSL.SP.2000.169.01.03

https://doi.org/10.1144/GSL.SP.2000.169.01.03

https://journals.sagepub.com/doi/full/10.2993/0278-0771-33.2.170

https://doi.org/10.2993/0278-0771-33.2.170

https://amazon.com/dp/1107057647/

https://www.frontiersin.org/journals/earth-science/articles/10.3389/feart.2021.648605/full

https://doi.org/10.3389/feart.2021.648605

https://www.sciencedirect.com/science/article/abs/pii/S0169555X08002407

https://doi.org/10.1016/j.geomorph.2008.05.039

https://www.asa3.org/ASA/PSCF/2016/PSCF12-16Complete.pdf

https://cir.nii.ac.jp/crid/1573668925015894016

https://amazon.com/dp/0195050142/

https://www.annualreviews.org/content/journals/10.1146/annurev-earth-032320-111432

https://doi.org/10.1146/annurev-earth-032320-111432

https://core.ac.uk/download/pdf/4269479.pdf

https://pubs.geoscienceworld.org/gsa/books/book/159/chapter-abstract/3790980/Development-of-monoclines-Part-II-Theoretical

https://doi.org/10.1130/MEM151-p273

https://pubs.geoscienceworld.org/gsa/books/book/159/chapter-abstract/3790978/Development-of-monoclines-Part-I-Structure-of-the

https://doi.org/10.1130/MEM151-p235

https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2012TC003107

https://doi.org/10.1029/2012TC003107

http://isgenesishistory.s3.amazonaws.com/digital%20downloads/earth-catastrophic-past-1-preview.pdf

https://assets.answersingenesis.org/doc/articles/pdf-versions/rock-layers.pdf

https://assets.answersresearchjournal.org/doc/articles/arj/v14/bright-angel-formation-supplement.pdf

https://assets.answersingenesis.org/doc/articles/arj/v14/tapeats-sandstone-supplement.pdf

https://assets.answersingenesis.org/doc/articles/arj/v15/muav-formation-supplement.pdf

https://answersresearchjournal.org/geology/carbon-canyon-fold-arizona

https://answersingenesis.org/geology/grand-canyon/fight-53-rocks

https://peacefulscience.org/books/grand-canyon-monument-ancient-earth/

https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/94TC02451

https://doi.org/10.1029/94TC02451

https://amazon.com/dp/1882054105/

https://www.sciencedirect.com/science/article/abs/pii/S0191814199000899

https://doi.org/10.1016/S0191-8141(99)00089-9

https://amazon.com/dp/B008Y02PS8/

https://pubs.geoscienceworld.org/sepm/jsedres/article-abstract/64/2a/324/98581/Precipitation-rates-for-quartz-cement-in

https://doi.org/10.2110/jsr.64.324