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RESEARCH

Bioturbation: Worm burrows and geological time

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Abstract

In the study of earth history one of the important goals is to understand how much time was involved in producing the principal fossil-bearing sediments of the Phanerozoic. The research reported here examines one measure of time that can be compared with the time indicated by radiometric dating. On the earth today animals and plants are continually burrowing into the substrate, and this disturbance is called bioturbation. Bioturbation can, in time, homogenize the sediment, destroying any record of the boundaries between layers of sediment. In the modern world the rate of this process can be measured, and bioturbation generally homogenizes the sediment in hours, days, or weeks. Under normal environmental conditions it does not take years. To quantify this process in the rock record we measured vertical sections through 37 sedimentary formations in western United States, from Cambrian to Eocene, recording the amount of observed bioturbation on these rocks. In all measured sections, 97% of the thickness showed no bioturbation or occasional isolated burrows. The remaining 3% of the vertical surfaces contained some bioturbation, with a very small amount (<1%) being thoroughly bioturbated. Such a low level of bioturbation is inconsistent with sediment accumulation over the time indicated by radiometric dating.

Introduction

As we seek to understand earth history, the fossil record, and their relationship to origins, one important factor to deal with is time: how can we best measure the amount of time in the Phanerozoic geological record? We cannot go back in history and directly measure time. Even radiometric dating cannot do that. It will be useful to have other indicators of the passage of time that we can measure today, and then apply to the geological record with an acceptable level of confidence. We quantified bioturbation through the geological column as one measure of how much time passed as the sedimentary record formed.

Today, sedimentary processes deposit layers of sediment in rivers, lakes, nearshore marine environments, and others. These sediment layers do not remain undisturbed. A host of small animals burrow through these sediments looking for food, plant roots grow through them, and erosion processes disturb them **(1)**. The rates at which these processes churn the sediments and erase clear evidence of the boundaries between sediment layers is the subject of much research. This research provides a quantified measure of how much time it takes to erase the boundaries between sediment layers and leave behind homogenized sediment. Even terrestrial sediments are processed in similar manner by mice, gophers, squirrels, insects, other terrestrial invertebrates, including a myriad of worms and by plant roots. We think that these modern analogues can be compared directly to ancient sediments formed in similar environments.

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With this background we conducted an extensive survey of a select sample of sedimentary formations from Cambrian to Eocene in western USA, including Utah, Arizona, and Colorado, quantifying the frequency and intensity of bioturbation in each formation. We predicted, based upon described experimental rates of bioturbation in the present environment, that sediments deposited on a time scale of millions of years, or even hundreds of thousands of years, would be thoroughly bioturbated, and divisions between individual layers of sediment would be largely obliterated by this process. On the other hand, sediments deposited rapidly, especially if deposited during a large-scale catastrophe, would likely have few intervals of intense bioturbation. But even under these conditions we would expect that there would be organisms in the water or transported with the sediment, seeking a place to settle. Consequently, we would expect some bioturbation, but probably not long intervals of intense bioturbation.

There are conditions that can interfere with bioturbation. A lack of oxygen in the water can reduce bioturbation, because many animals cannot live there **(2–5)**. It is also recognized that if the sediment was deposited so rapidly that not much animal activity could occur, this would prevent or greatly reduce bioturbation **(6,7)**. We will discuss how each of these is likely to relate to the sedimentary record.

Methods

We used standard procedures to measure sections through each of the studied formations, documenting the amount of bioturbation in adequately exposed intervals, centimeter by centimeter. We measured rock thickness using a Jacobs staff with an Abney level for accuracy **(8)**. Intensity of bioturbation was categorized according to the scale in **Figure 1** and illustrated in **Figure 2**. This scale is a modification of the ichnofabric index used by Droser and Bottjer **(9)**, modified to suit our research design. The bioturbation measured in this study was primarily seen on vertical or nearly vertical surfaces, not on horizontal surfaces. This design was chosen as a practical matter because rock exposures suitable for measuring a section seldom had many horizontal exposures for quantifying bioturbation. We made the assumption that the level of bioturbation seen on vertical surfaces will provide a sufficient estimate of the amount of bioturbation to be expected on horizontal surfaces in the same interval. In addition, our primary goal was to understand how often there was sufficient bioturbation to obliterate the boundaries between sediment layers. For this purpose, bioturbation on horizontal surfaces is not as pertinent.

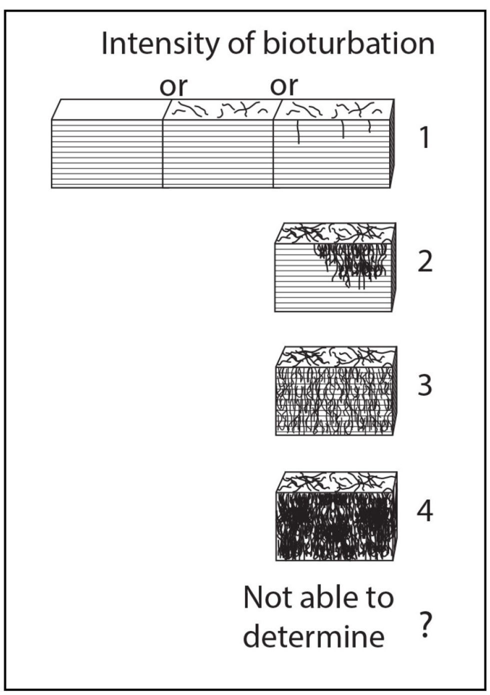


Figure 1. Scale of bioturbation used in this research. The question mark indicates intervals that were covered or obscured, where we could not evaluate bioturbation.

The scale in **Figure 1** does not begin with zero bioturbation. This is because we had no measure of bioturbation on horizontal surfaces, and thus we could not document a level of zero bioturbation. Also, since we would not be surprised if some bioturbators were present, even with rapid deposition, we did not expect to see zero bioturbation as a rule. Our scale is designed to measure the extent to which sediment layering was obscured by bioturbators, as would be expected with the passage of time. The first level included the possibility of a small amount of vertical burrowing, but not enough to have much effect on the sediment layers. Levels two and three are intermediate bioturbation levels, and level four

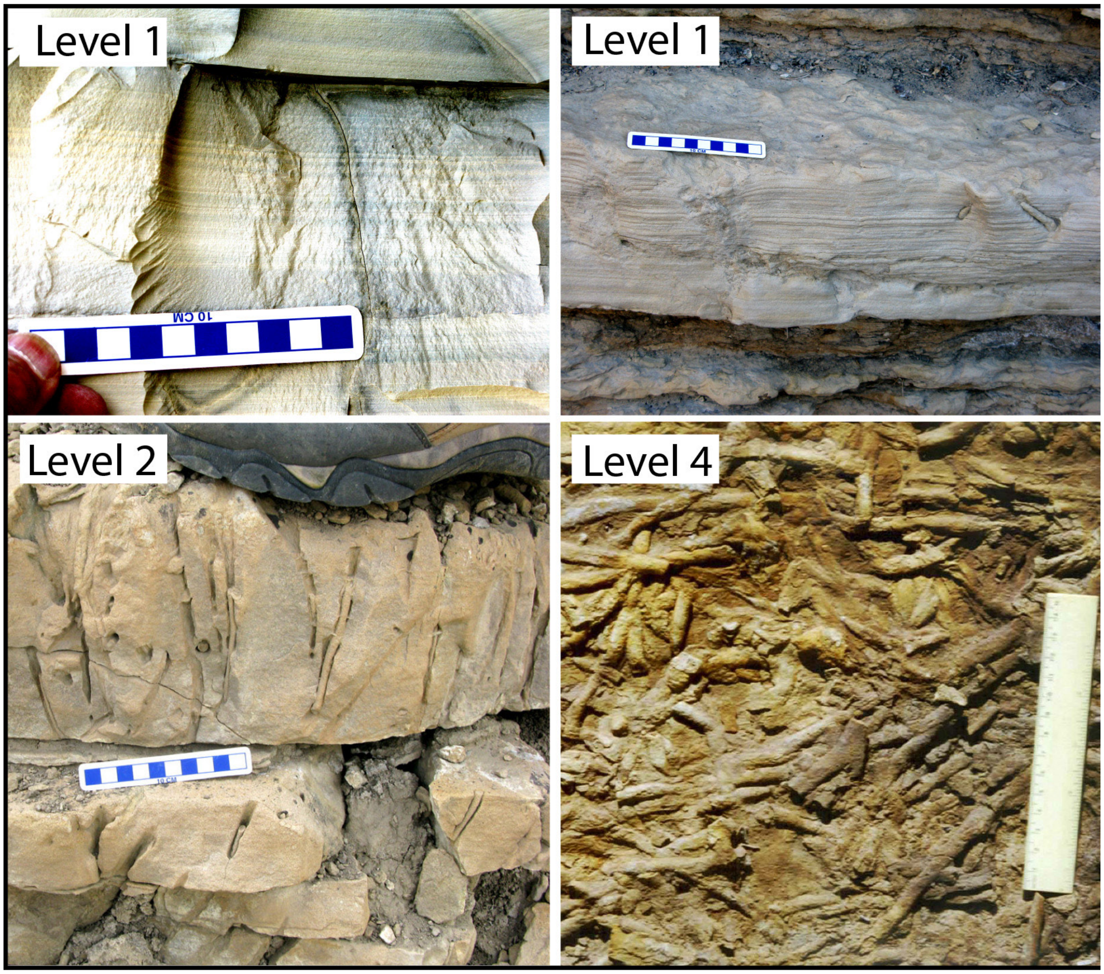


Figure 2. Examples of different levels of bioturbation, as defined in Figure 1.

is bioturbation that fully obscures sediment layering. In uniformitarian geological processes, we expect that level four would be the most common, as it usually is during modern processes **(10)**.

Using this method, we surveyed bioturbation in 37 geological formations, selected to sample the Phanerozoic record, from Cambrian to Eocene. **Figure 3** is a record of the sampled formations and their position in the geological column. The vertical extent, in meters, of bioturbation in levels one to four was determined in all 37 formations that we measured. Some formations were surveyed at several different locations. For each of these formations we used a maximum of two sections in our calculations. This resulted in the use of 46 sections. **Table 1** describes the location of each study site.

Study sites were chosen for clean rock surfaces over as much of each section as possible, accessibility of the site, and practical access to the entire section without risk of bodily injury. Figure 4 shows researchers at several study sites. A variety of sediment types were surveyed, including limestone, dolomite, shale, mudstone, and sandstone. **Figure 5** has photographs of several study outcrops.

Figure 3. The rock formations we surveyed, and their position in the geological column. Red symbols indicate approximate levels at which we documented at least some bioturbation.

Labels such as "M2" allow correlating this list with locality information in **Table 1.**

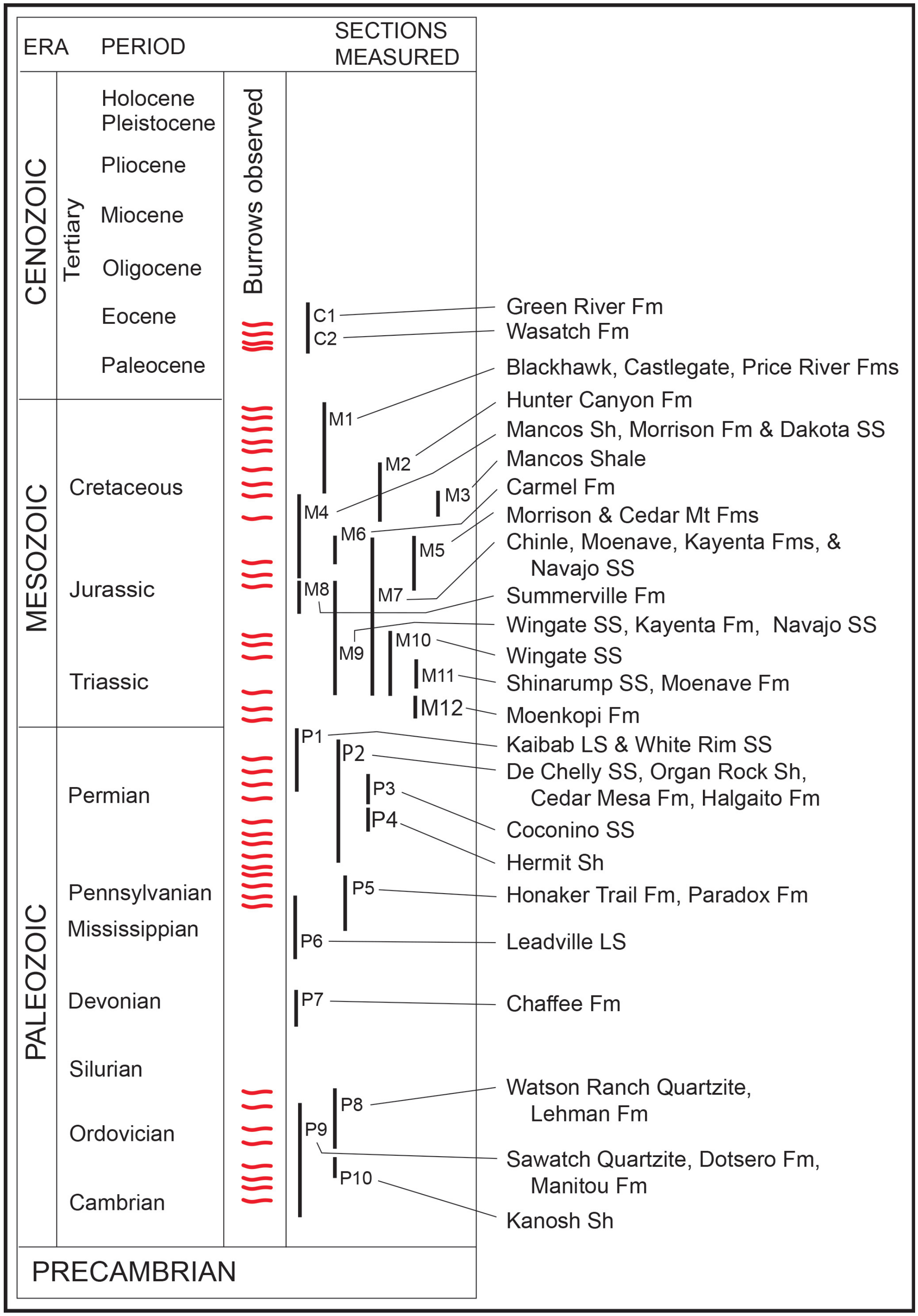


Table 1. Locality information for **Figure 3.**

C1.	Rifle, Colorado. Green River Fm, Eocene.
C2.	Rifle, Colorado. Wasatch Fm, Eocene.
M1.	Price, Utah. Blackhawk Fm, Castlegate Fm, Price River Fm, Cetaceous.
M2.	Northeast of Grand Junction, Colorado. Hunter Canyon Fm, Cretaceous.
M3.	San Rafael Swell, I 70, 54 miles west of Green River, Utah. Mancos Sh, Cretaceous.
M4.	East side of Capital Reef N P, Burr Trail, Utah. Mancos Sh, Morrison Fm, Dakota SS, Jurassic.
M5.	San Rafael Swell, I 70, 20 miles west of Green River, Utah. Morrison Fm, Cedar Mt Fm, Jurassic.
M6.	San Rafael Swell, I 70, 20 miles west of Green River, Utah. Kayenta Fm, Carmel Fm, Navajo SS, Triassic to Jurassic.
M7.	Cockscomb monocline, 20 miles east of Kanab, Utah. Chinle Fm, Moenave Fm, Kayenta Fm, Navajo SS, Triassic to Jurassic.
M8.	East side of Capital Reef N P, Burr Trail, Utah. Summerville Fm, Jurassic.
M9.	East side of Capital Reef N P, Burr Trail, Utah. Wingate SS, Kayenta Fm, Navajo SS, Triassic to Jurassic.
M10.	Kanab, Utah. Wingate SS, Triassic.
M11.	Hurricane Mesa, 24 miles northeast of St George, Utah. Shinarump Conglomerate, Triassic.
M12.	Hurricane Mesa, 24 miles northeast of St George, & San Rafael Swell, I 70, 54 miles west of Green River, Utah. Moenkopi Fm, Triassic.
P1.	San Rafael Swell, I 70, 54 miles west of Green River, Utah. Kaibab LS, White Rim SS, Permian.
P2.	Comb Ridge, 13 miles southwest of Blanding, Utah. De Chelly SS, Organ Rock Sh, Cedar Mesa Fm, Halgaito Fm, Permian.
P3.	Grand Canyon, Arizona. Coconino SS, Permian.
P4.	Virgin River Gorge (Arizona), 8 miles southwest of St George, Utah. Hermit SS, Permian.
P5.	Goosenecks State Park, 5 miles west of Mexican Hat, Utah. Honaker Trail Fm, Paradox Fm, Pennsylvanian.
P6.	Glenwood Springs, Colorado. Leadville LS, Mississippian.
P7.	Glenwood Springs, Colorado. Chaffee Fm, Devonian.
P8.	Fossil Mountain, 50 miles southwest of Delta, Utah. Watson Ranch Quartzite, Lehman Fm, Ordovician.
P9.	Glenwood Springs, Colorado. Sawatch Quartzite, Dotsero Fm, Manitou Fm, Cambrian to Ordovician.
P10.	Fossil Mountain, 50 miles southwest of Delta, Utah. Kanosh Sh, Ordovician.

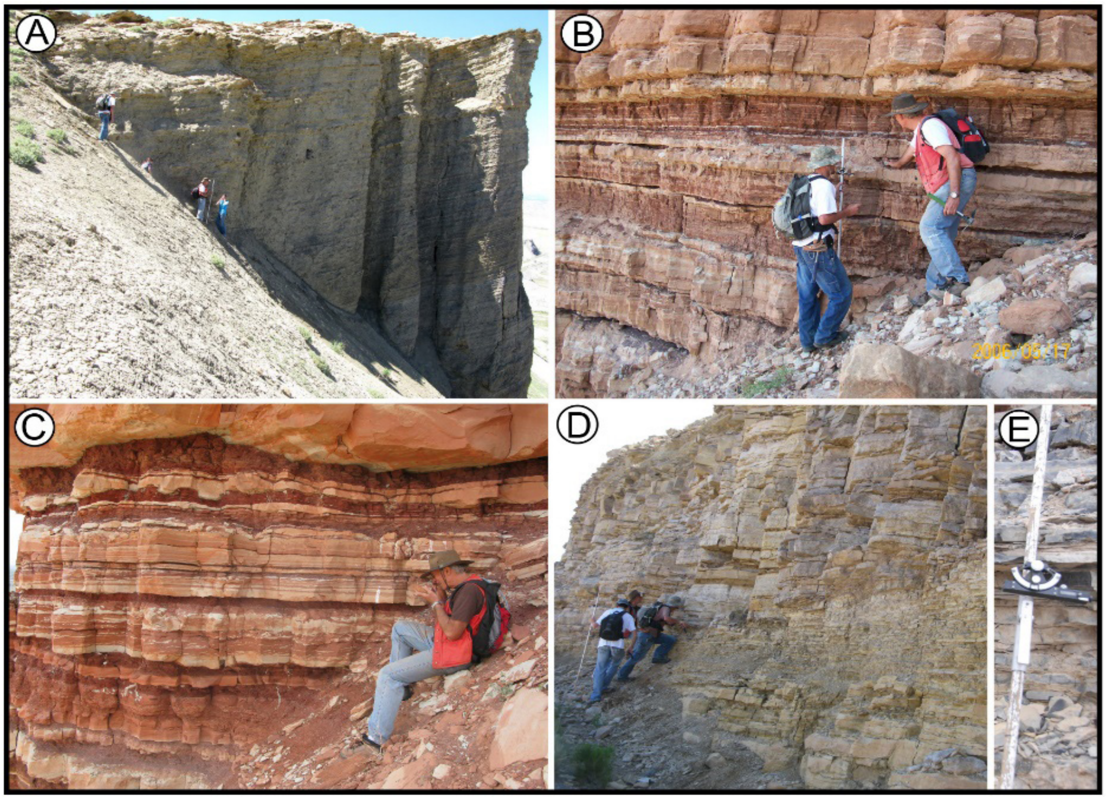


Figure 4. Researchers at representative study sites.

A: Cretaceous Mancos Shale., Caineville, Utah; **B**: Jurassic Summerville Fm, east side of Capital Reef N.P, Utah; **C**: Jurassic Moenave Fm., Kanab, Utah; **D**: Triassic Moenkopi Fm., San Rafael Swell, I 70, 54 miles west of Green River, Utah; **E**: the Jacobs staff with Abney level we used.

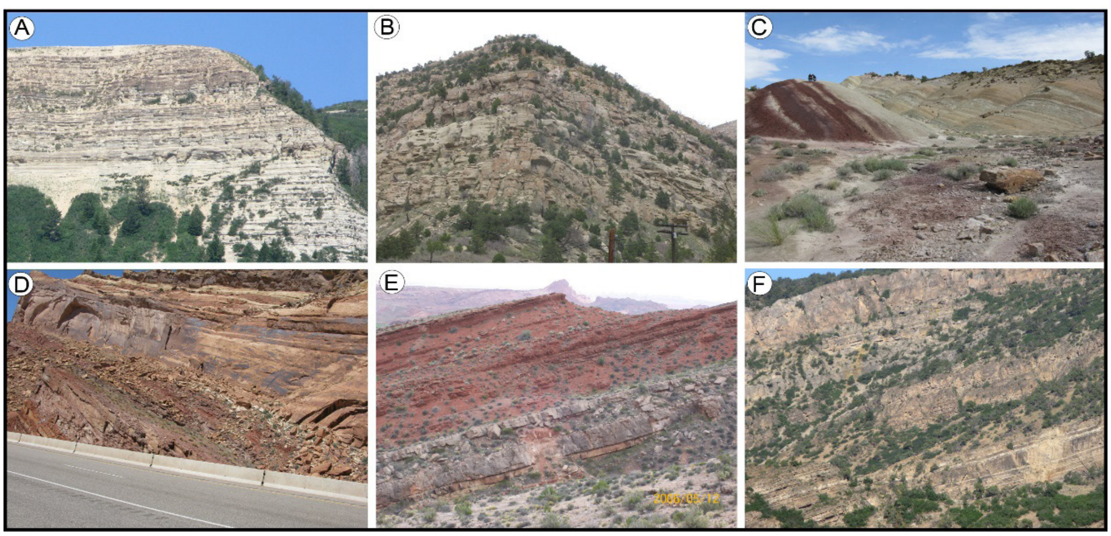


Figure 5. Representative outcrops used in this research.

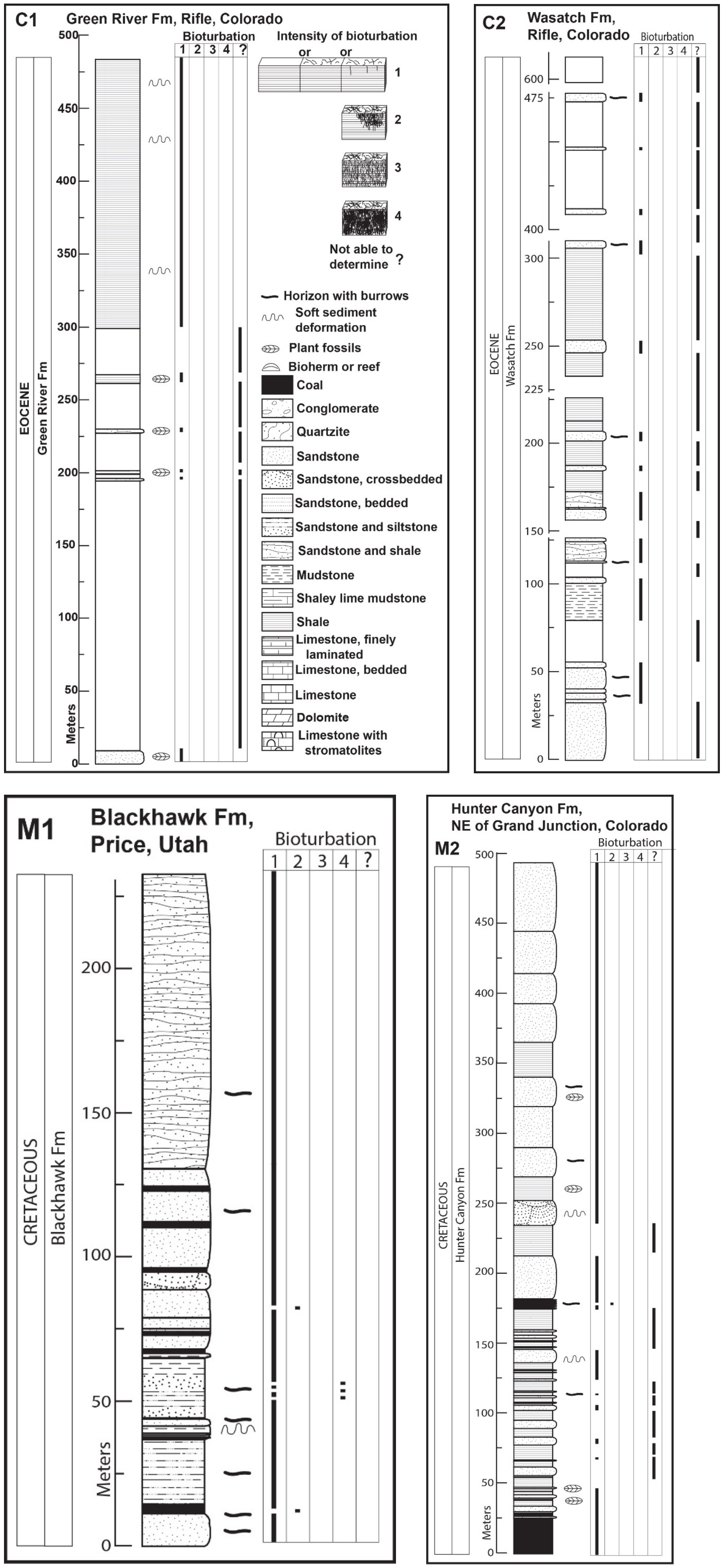
A: Eocene Green River Formation, Rifle, Colorado; **B**: Cretaceous Price River Fm., Price, Utah; **C**: Upper Jurassic Morrison Fm., east side of Capital Reef N P, Utah., **D**: Lower Jurassic Wingate SS, San Rafael Swell, I 70, 20 miles west of Green River, Utah; **E**: Permian Comb Ridge, 13 miles southwest of Bluff, Utah; **F**: Cambrian-Ordovician, Glenwood Springs, Colorado.

See **Figure 4** for additional outcrops.

Results

Figure 6 shows our results for ten representative measured sections. These sections were chosen to include the maximum and the minimum amount of bioturbation for all our measured sections. The information on the right side of the Green River Fm. section applies to all the sections. Portions of sections labeled "?" were obscured (covered by vegetation or talus) or otherwise did not provide adequate detail for analyzing bioturbation. The largest amount of obscured section in our study was found in the Eocene formations, which were exposed on steep hillsides. Column on the left in each diagram contains symbols indicating the primary type of sediment in each part of the section.

Figure 6. Amount of bioturbation in ten measured sections, selected to show the range of bioturbation density seen in the entire study. Sections are arranged in descending stratigraphic order. Symbols such as "M2" are the symbols used in **Figure 3** identifying each section. Blank portions of the stratigraphic columns represent intervals that were too obscured to be sure of the type of sediment.



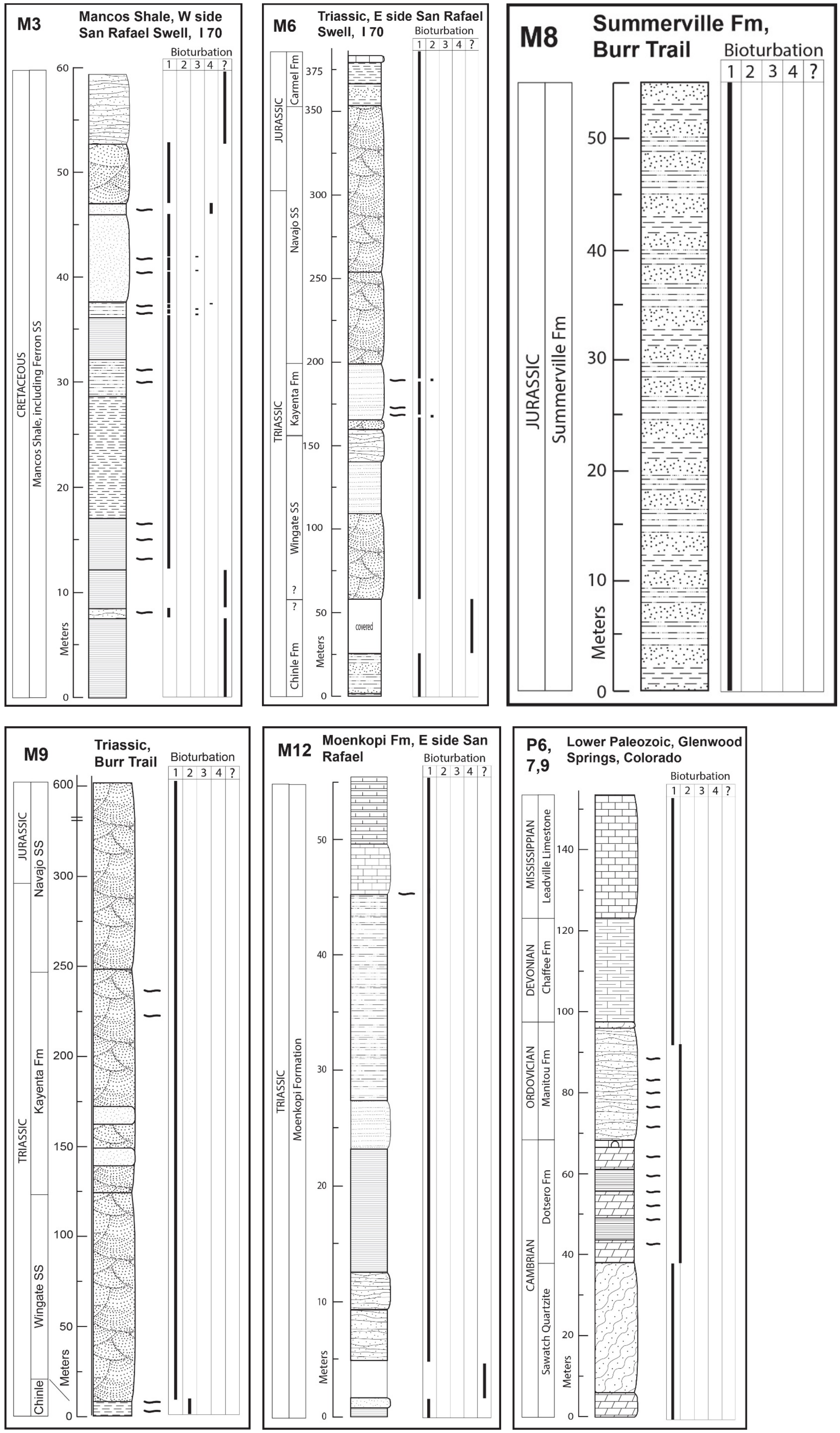

M3
Mancos Shale, W side San Rafael Swell, I 70
Bioturbation
1 2 3 4 ?
CRETACEOUS
Mancos Shale, including Ferron SS
Meters
0
10
20
30
40
50
60
M6
Triassic, E side San Rafael Swell, I 70
Bioturbation
1 2 3 4 ?
JURASSIC
Carmel Fm
Navajo SS
TRIASSIC
Kayenta Fm
Wingate SS
Chinle Fm
covered
Meters
0
50
100
150
200
250
300
350
375
M8
Summerville Fm, Burr Trail
Bioturbation
1 2 3 4 ?
JURASSIC
Summerville Fm
Meters
0
10
20
30
40
50
M9
Triassic, Burr Trail
Bioturbation
1 2 3 4 ?
JURASSIC
Navajo SS
TRIASSIC
Kayenta Fm
Wingate SS
Chinle
Meters
0
50
100
150
200
250
300
600
M12
Moenkopi Fm, E side San Rafael
Bioturbation
1 2 3 4 ?
TRIASSIC
Moenkopi Formation
Meters
0
10
20
30
40
50
P6, 7,9
Lower Paleozoic, Glenwood Springs, Colorado
Bioturbation
1 2 3 4 ?
MISSISSIPPIAN
Leadville Limestone
DEVONIAN
Chaffee Fm
ORDOVICIAN
Manitou Fm
CAMBRIAN
Dotsero Fm
Sawatch Quartzite
Meters
0
20
40
60
80
100
120
140

Table 2. Percent of all measured sections in each bioturbation level. Number of occurrences indicates the number of measured sections in which this bioturbation level was seen at least once. Percent of total is percent of vertical distance of all sections that were in each bioturbation level (including only portions of the section that were not obscured).

Bioturbation level	1	2	3	4
Meters of section	5,172	138	19	4
Number of occurrences	46	7	3	2
Percent of total	97	2.6	0.36	0.09

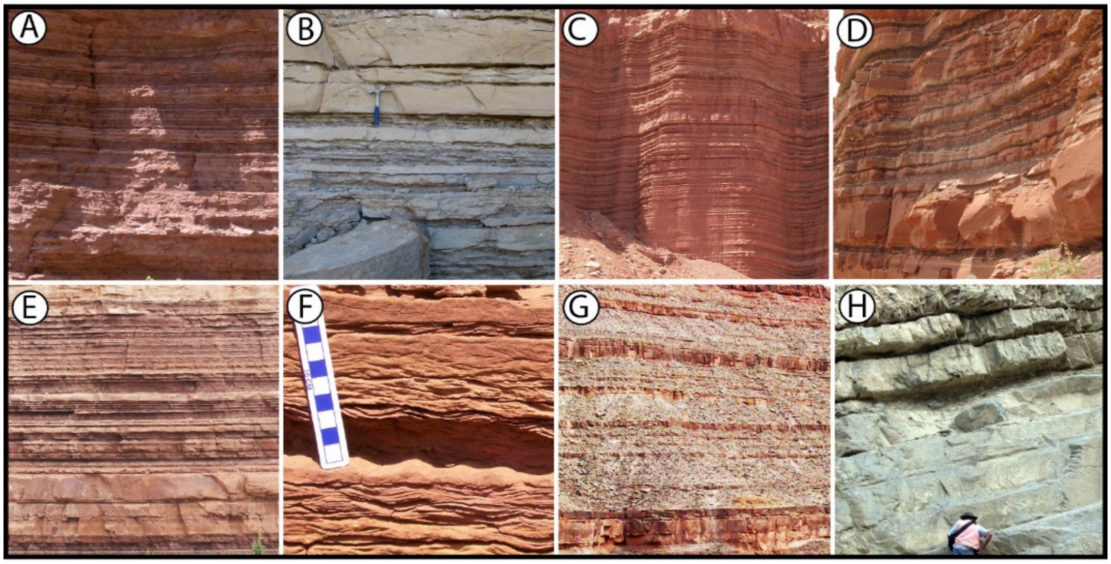


Figure 7. Typical well-preserved bedding in our study sections. **A**: Cretaceous Mancos Sh.; **B**: Ferron SS, part of the Mancos Sh.; **C**. Jurassic Summerville Fm.; **D**: Triassic Chinle Fm.; **E** and **F**: Triassic Moenkopi Fm.; **G**: Pennsylvanian Honaker Trail Fm.; **H**: Mississippian Leadville LS.

Scale in **F** is ten cm. All others are seen in outcrop scale – meters to tens of meters.

For each section, the vertical distance (in meters) of the total section was determined, and also the vertical distance of the portion of that section that was not obscured. For all measured sections combined, the vertical distance (in meters) in each bioturbation level was divided by the total number of meters of the non-obscured portions of all sections. This gave the percentage of all sections combined that were in each bioturbation level (**Table 2**). Ninety seven percent of all sections were in bioturbation level one, and lesser percentages in levels 2-4. For some formations, more than one section was measured, at different localities. For each of these formations only two sections were used in the calculations.

Throughout the geological formations that we surveyed, the bedding in all sections is very well preserved. Boundaries between beds are intact and have not been destroyed or seriously damaged by bioturbation. **Figure 7** includes typical examples of the bedding in representative formations that we studied.

Discussion

From the evidence we collected it is evident there is very little bioturbation in our sampled sections, from Cambrian to Eocene. There are other locations in the geological record that have more bioturbation than this, including in the middle Paleozoic, but the results presented here are what we found in our sample. There are scattered examples of bioturbation, but very few cases of intense, level four bioturbation, and they are limited in vertical extent. This is consistent with our predictions if the sediments were deposited in rapid succession with little time for bioturbation, but very different from the predictions of uniformitarian processes involving slow deposition over long periods of time. Examples of intense bioturbation are not extensive enough to obscure a significant amount of the sediment layering, as seen in **Figure 7**. This is not surprising, considering how little bioturbation there is in all these studied outcrops. This aspect of the geological record is very different from what happens in the modern world. If the uniformitarian assumption that processes forming ancient rock formations were comparable to processes today in rivers, flood plains and other environments was true, the boundaries between these beds would all or mostly have been destroyed **(10)**.

The measure of time that most of the scientific community has confidence in is radiometric dating. Physicists have developed an understanding of the radiometric isotopes, and decay sequences from one to another. They have also measured the decay rates in the laboratory. We don't see reason to question that part of the method. The uncertainties, we suggest, come from other aspects of the method, such as the unknown history of each rock sample.

Since the radiometric dating method gives ages that are compatible with the other assumptions accepted by a uniformitarian approach to earth history, confidence in this method is not surprising and might seem to be warranted. However, it will be very beneficial to have some other methods for measuring the passage of time, that yield estimates of time in the geological record that can be compared with radiometric dates, without undue dependence on assumptions **(11)**. Twidale said, "At present, physical dates do not stand on their own. They must be compatible with stratigraphy. Stratigraphy has also served to highlight flaws and the relevance of unexpected factors in some physical procedures. So-called absolute dating is a misnomer, for physical dates provide numerical approximations, preferably considered within and constrained by a stratigraphic framework."

One such method is evidence for the life activities of organisms (such as bioturbation) in the fossil record. This evidence should give us an insight into the amount of time involved; how fast these activities occur, and how much time is indicated by these data.

Today bioturbating organisms are extremely common and continuously active. Measured bioturbation intensity or rates indicate that divisions between newly deposited sedimentary layers are destroyed in hours, days, or weeks, as bioturbators homogenize the sediment. It does not normally take years. An experimental study showed complete homogenization of sediments down to a depth of 10 cm in an hour if bioturbators are abundant **(12)**. This is not unrealistic, since some small bioturbators can reach 16,000 to 60,000 individuals per square meter **(13)**. This is not the usual abundance, but bioturbation clearly does not require long time periods. Another experimental study of bioturbation found that a small number of marine organisms that feed while moving through the sediment can bioturbate a square meter plot in an hour to 42 days (**6**). In some cases there is seasonal alternation between highly bioturbated units, and units with laminated beds because of a lack of active bioturbation **(14)**, as observed in study of a modern river.

One prominent bioturbation researcher **(10)** concluded that "one hundred percent bioturbation of the substrate is the natural end-product of the activity of bioturbating organisms." "Failure to reach 100 percent, or failure of that state to be preserved in the rock record, are conditions that require explanation" (p. 223-225). Since bioturbation today has been shown to completely process the sediment in a short time frame, we should expect to see this reflected in ancient sediments, if those sediments were deposited in a way that was similar to what happens today. If sedimentary rocks often contain distinct layering undamaged or minimally damaged by bioturbation, that does not seem to be consistent with the expectations of uniformitarianism, or even of neocatastrophism as understood today. This would be a condition that requires, according to Bromley, a serious level of explanation.

Two processes have been recognized as possible causes for limited bioturbation. One is lack of oxygen in the water, because many animals cannot live there **(2–5)**. It apparently requires truly anoxic conditions to prevent all bioturbation. A study of modern sediments off the coast of Peru found that bioturbation can be common in low oxygen conditions (hypoxia), but anoxic conditions in up to 15 cm of sediment resulted in laminated sediment with no bioturbation **(15)**. The other factor affecting bioturbation is rapid deposition of sediment, not allowing time for active bioturbation **(6,7,16).**

In the oceans today and apparently during the Quaternary, large areas of the ocean have low oxygen levels **(17,18)** and low biota. We would expect very little bioturbation there. Although oxygen can be limited in such situations today, this is not likely to be a widespread condition in areas of active, rapid deposition of sediment in shallow water in the past. On the other hand, extremely rapid sediment deposition is expected to occur during a global catastrophe, and we suggest that this was the primary factor limiting bioturbation during much of the sedimentary record. In such a consistently rapid process, bioturbators would likely be in the water, searching for a place to settle. We would expect them to leave some evidence, occasionally, as we found in our research, but areas of extensive bioturbation are rare in the sections we examined.

Bioturbation is the subject of very abundant research, much of it in modern environments, but also in the rock record. Some studies of the rock record report higher levels of bioturbation than we found. For example Tarhan et al. **(19)** studied outcrops of a Cambrian-Ordovician marine succession along the coast of Newfoundland, interpreted as deposited in a passive margin or shelf environment. That study is not directly comparable to ours, because their methods were quite different. They evaluated bioturbation on horizontal surfaces as well as vertical surfaces. They report bioturbation levels at some localities that were near their maximum level, level 6 on their scale. We also found some uncommon examples of bioturbation level 4, the highest level on our scale. They report finding, on average, higher levels of bioturbation than we found, but they state that "average levels of bioturbation along this margin remained low throughout much of this interval, relative to those of environmentally analogous seafloor settings in modern oceans." It would be instructive to search the rocks and the literature to determine what factors differ between formations with common bioturbation and those which, like our sample, have little bioturbation. However, it is likely that rock formations with rare bioturbation or rare body fossils will not often be the subject of published papers **(4).**

Consistent with the scarcity of serious bioturbation, the divisions between sedimentary layers in the geological column are persistently distinct and well-preserved. These have not been obscured by bioturbation and other routine processes that affect sediment and exposed ground surfaces today. The low level of disruption of laminated sediment by bioturbation as seen in **Figure 7** is an important verification of the low levels of bioturbation that we found in our sample. This is consistent with the expectations of rapid geological processes, which had only a small amount of time for each formation to be deposited, and very little time or no time passing between the deposition of successive layers. A comparative study of bioturbation through the Cenozoic could have potential to yield insights into the timing of the transition from catastrophic conditions in the flood to quieter conditions postflood.

The idea of a global catastrophe will be quickly dismissed by many persons, but the rapid processes during that global catastrophe are actually the only possible reason why the sedimentary layers have sufficient preserved details to allow geologists to seek to understand them at all. In a uniformitarian process, most of these sedimentary details should have been obliterated or damaged by bioturbation **(10)**, leaving little prospect for today's geologists to interpret the rocks. Much of the sought-for evidence would have been replaced with evidence of bioturbation. Sedimentologists may study the sedimentary structures preserved in outcrops without ever recognizing that the existence of these preserved features argue against a slow extended period of deposition.

Creationist interpretations of geological evidence are often attributed to lack of knowledge or closed-minded unwillingness to consider other options. For those who are experienced scientists the explanation can be very different. They understand the evidence, and how and why the evidence is usually interpreted the way it is. However, their minds are likely to be open to comparing different models (including models they don't like, and models not accepted by the general scientific community), and evaluating how effective each model is in explaining the evidence. This comparative approach allows us to recognize conflicts between the evidence and the accepted interpretations of this evidence, if there are such conflicts. For these individuals their willingness to compare such a diversity of models makes them more open-minded. That is what it takes to recognize the disconnect between the reality that we see in the geological record for bioturbation, and the standard interpretation of geological time. Our purpose in this work is not to prove we are right. Proof is not a realistic goal, and we don't need to prove our viewpoint. The evidence will speak for itself, if we allow it to. The only satisfying approach is to seek to know, in all fairness, what the evidence says about geological history.

Conclusions

In this research we sought to apply a fair-minded method to an analysis of the abundance of bioturbation through most of the geological column. In our random sample of rock formations we found a very low level of bioturbation from Cambrian to Eocene. There is much too little bioturbation in this sample to be compatible with the passage of the long time periods postulated in the standard geology paradigm. The meagre bioturbation record is consistent with the conditions and the brief time periods expected in a global geological catastrophe. This evidence is just what we would expect if the record in Genesis is true.

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