Investigating the Effect of Rock Conditions on Ordovician Fossil Properties in Nashville, Tennessee

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BRIEF. Fossils were counted and measured in three local outcrops, and these results were compared to the rock conditions in which they were found in order to assess biases in the fossil record.

ABSTRACT. Paleontology offers catalogues of environmental data via the fossil record. Mass extinctions, invasive species, and climate fluctuations in the distant past serve as reference points for modern conservation decision-making. The Ordovician period is a good ecological analogue as it is characterized by high rates of speciation. The fossil record is subject to bias, however, as patterns in which sediment and fossils are deposited can over or underrepresent certain species and mix them with species of other time periods. Here rock patterns indicative of weathering conditions may have overrepresented Ordovician invertebrate fossils, as the average number and length of fossils in weathered rock conditions were significantly greater than those in conditions of massive/shear rock. Such data could warrant a reevaluation of fossil records sourced from the specific rock conditions here studied. Unique phyla/classes and rock conditions of each location suggest slightly different paleoenvironments. High numbers of small (<0.3cm), complete fossils in one location suggest alternate effects of the pressure of multiple layers of rock on invertebrate fossils. These findings further catalogue Ordovician paleoecology and could aid in accounting for biases in future studies.

INTRODUCTION.

Paleontology is critical to our understanding of evolution and modern ecology [1]. Fossil data from ancient ecosystems provides insight into present, analogous ecological patterns and vulnerabilities. Current research on mass extinctions by Darroch et. al and Jablonski and Shubin has the potential to inform conservation actions as climate change exacerbates [2-3]. The fossil record can even serve as an archive for past climate data and has provided insight on modern resource management [4-5]. Such resource management and retrospective knowledge on the inner workings of climate change aids in preserving biodiversity as it declines in the face of climate change. Thus, the relevance of paleontology and of understanding paleoecology is greater now than ever before.

A significant ecological analogue is the Ordovician period, due its high biodiversity and predominantly marine biome. High biodiversity has been linked with high environmental stress [6], a descriptor that applies to the stress levied on modern ecosystems and organisms by climate change. Kempf et al. studied a biological invasion caused by the unification of previously isolated basin ecosystems due to rising sea levels [7]. Such an event likewise echoes what may occur in coming years due to climate change.

A central debate regarding the impact of biases on any fossil record—including the Ordovician—is almost as old as the field of paleontology itself, as outlined by Holland and Patzkowsky [8]. Behrensmeyer has further specified conditions required for fossilization and preservation—steady or suddenly high sediment deposition, low ecological efficiency, etc.—that can exclude or overrepresent species in the fossil record [9]. Even when a fossil forms and subsequently resists lithification bias—the intense pressure of multiple strata that destroys many smaller fossils [10]—tectonic shifts and other geological processes can further distort a literal interpretation of the fossil record [8, 11]. Subfields have arisen [8] including stratigraphic paleobiology, which explores the geological processes biasing the fossil record by analyzing patterns in the strata (layers of sediment deposition) in which fossils are preserved [8, 11]. Using stratigraphic paleobiology, paleontologists can make more accurate conclusions regarding paleoecology and evolutionary processes that benefit the understanding and conservation of present ecology.

Catalogues of Ordovician rock stratigraphy already exist [11, 12], in addition to general outlines of Ordovician paleoecology. Kempf et al. found significant differences in food web structure before and after a well-documented invasion in the Ordovician to gain insight in modern invasive species events whose long-term effects are harder to document [7]. Their findings included reference to the stratigraphic patterns in the areas from which they sourced fossils. Other research documents stratigraphic patterns without reference to how geologic processes may have biased the fossil record housed within said strata [8, 11, 13]. This research builds upon these works with a comparison of the number and length of photographed fossils in select square meters of three local outcrops, and provides conclusions on possible geological reasons for the results. It is expected that the rock conditions of each source outcrop will have a significant effect on observed average fossil size, even if this effect can be most likely attributed to lithification and other stratigraphic biases rather than properties of the paleoecology. The rock conditions in question included interbeds and/or laminate—both rock features indicative of calm, deep depositional environments [14-16]—massive conditions, in which the rock is somewhat featureless either due to rapid, storm-borne sediment deposition or subsequent shearing by geologic forces, and weathering conditions, in which the surface rock is particularly brittle and/or worn [17].

MATERIALS AND METHODS.

Location selection and measurement.

Three Nashville outcrops were chosen in which invertebrate fossils were counted. These outcrops were located at 36.13°N, -86.89°W (Location 1), at 36.03°N, -86.74°W (Location 2), and at 36.19°N, -86.79°W (Location 3), respectively. These locations were selected due the variety of stratigraphic properties observed between outcrops during a two-week scouting period. Outcrop length and height were also measured during the scouting period, and approximate outcrop surface areas were calculated for later comparison with average fossil counts per square meter. All measurements in this project were taken by photographing the outcrop/fossil/subject with a scaled object (sections of a 150cm tape for outcrop height measurements, a scale bar in pictures of the locations in Google Maps for outcrop length measurements, and a nickel for fossil measurements) and analyzing the resulting images via Fiji/ImageJ version 2.1.0/1.53c for Mac [18].

Location sectioning.

In outcrops where the height was variable, sections distinguished from the others by height differences of 1 meter or greater were given individual area measurements to increase the accuracy of approximate surface area calculations. Thus, the outcrop at Location 1 (approximately 160.44 meters in total length) consisted of three sections—85.05, 40.64, and 30.62 meters in length—with approximate continuous heights of 6.3, 5.16, and 3.83 meters, respectively. Section length measurements do not add up directly to the total outcrop length because ImageJ could not measure the outcrop itself and sections of the total measurement

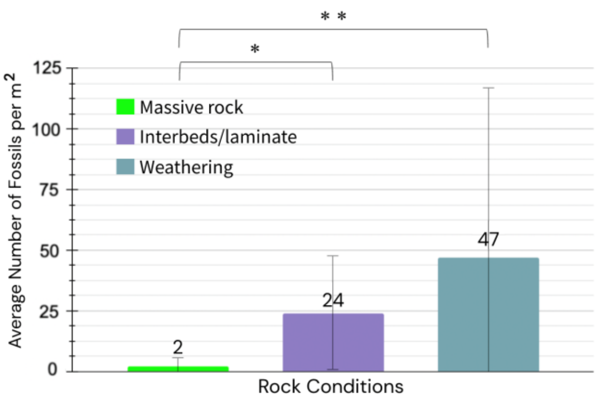

Figure 1. The average number of fossils/m² in different rock conditions. Fossils were counted in 48 m which were sorted by the rock conditions above. The most fossils on average were found in conditions of Weathering (N=18 m²), followed by Interbeds/laminate (N=19) and Massive rock (N=11). STDEV for each data point from left to right 3.58, 23.41, 70.27. A Kruskal-Wallis test found significant differences between the treatments (α=0.05, p-value=0.0021, H=12.31). Post-hoc Dunn's testing (α=0.05) confirmed this difference, but only when comparing Massive rock to other groups: * p-value=0.0014, ** p-value=0.0001, Interbeds/laminate vs Weathering p-value=0.4578.

simultaneously. Instead, landmarks and a picture of the total outcrop length were used for reference during individual section measurement.

As there seemed to be a similar trend of fossil distribution during early fossil counting, initial sectioning was conducted. In addition to a more accurate approximate surface area calculation, this allowed for categorization of where on each outcrop fossils were found. Sectioning also allowed for comparisons in average fossils per square meter of surface outcrop using surface area totals during subsequent analysis.

Fossil counting.

Fossils were counted and stratigraphic conditions were noted along the bottom square meter of each outcrop to record general fossil-stratigraphic data/trends. Rather than count out all ~350 total meters of outcrops, fossils were counted in 6 square meters of each outcrop section less than 60 meters in length. In sections greater than 60 meters in length, fossils were counted in 12 square meters—this was to promote greater accuracy in gathering a sample of fossil distribution in larger sections. For the same reason, half of the square meters were counted on one end of all sections, and half were counted on the opposite end. Each square meter was measured out with measuring tape, its top corners marked by sticking a stylus into the rock, so that any fossils outside these boundaries were not included in final counts for that square meter. Groups of 3 or 6 square meters were scanned for fossils consecutively and toward the same direction in each group to reduce potential duplicate square meters.

Fossil measurement.

Fossils were counted and measured using ImageJ. Whenever a fossil or fossils was found in a square meter, a picture was taken with an iPhone SE camera. Included in every picture was a nickel near and on relatively the same plane as the fossil, tails side up. These pictures were later analyzed using the Set Scale and Measure features in ImageJ. The scale in every image was set by drawing a line in ImageJ through the nickel along the bottom of the Monticello building—this length is approximately 2.2 cm—and setting the pixel length of this line as equivalent to 2.2 cm using the Set Scale feature. With that scale, ImageJ could then use the Measure feature to extrapolate the lengths of lines drawn on photographed fossils. Fossil length was measured as the longest exposed length of a fossil, or the distance from the hinge to the outer edge of the shell for brachiopods and bivalves.

To account for slight differences in depth behind the coin that might bias length measurements, the coin was aligned on a similar plane with a fossil in each photo. In photos containing multiple fossils, the coin was aligned in the way that most closely matched as many fossils as possible. Fossils that did not align with the majority were considered in separate pictures, in which the coin was more closely aligned with them.

Rock properties and data analysis.

The stratigraphic characteristics of each square meter were noted for later categorization. Stratigraphic categories considered in this study included interbeds and/or laminate, flat shear conditions, and weathering conditions. Statistical analyses—Kruskal-Wallis One-Way ANOVAs and post-hoc Dunn's tests—were run comparing average fossil length and number per square meter to stratigraphic conditions in corresponding square meters. This was done to evince whether some stratigraphic characteristic tested for influenced fossil properties.

RESULTS.

Most fossils were found in conditions of weathering.

Figure 1 shows the average number of fossils/m² counted in three different rock conditions across the three locations in which fossils were counted. The highest average number of fossils/m² was found in conditions of Weathering, followed by Interbeds/laminate and Massive rock. A Kruskal-Wallis test followed by a post-hoc Dunn's test with α=0.05 found significant differences between the rock conditions, with the overall p-value and H statistic being 0.0021 and 12.31, respectively. There was a significant difference between the average number of fossils/m² in Massive rock and Interbeds/laminate (p-value= 0.0014), and a significant difference between Massive rock and Weathering (p-value=0.0001).

Largest fossils were found in conditions of weathering.

Figure 2 shows the average length in centimeters of fossils/m² in three different rock conditions across the three locations in which fossils were counted. The highest average length of fossils/m² was found in conditions of Weathering, followed by Interbeds/laminate and Massive rock. A Kruskal-Wallis test followed by a post-hoc Dunn's test (both with α=0.05) found significant differences between the rock conditions, with the overall p-value and H statistic being 0.0292 and 7.066, respectively. There was a significant difference between the average number of fossils/m² in Massive rock and Weathering (p-value=0.0105).

DISCUSSION.

Differences in average number and size.

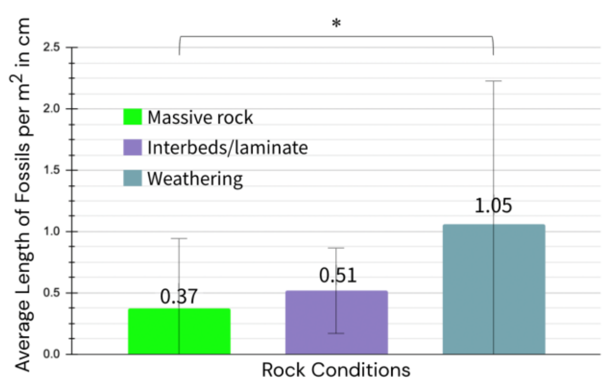

Figure 2. Average fossil length (in cm) in different rock conditions. Fossils were measured in 48 m² and their average length/m² was sorted by the rock conditions above. The largest fossils on average were found in conditions of Weathering (N=18 m²), followed by Interbeds/laminate (N=19) and Massive rock (N=11). STDEV for each data point from left to right: 0.57 cm, 0.35 cm, 1.17 cm. A Kruskal-Wallis test found significant differences between the treatments (α=0.05, p-value=0.0292, H=7.066). Post-hoc Dunn's testing (α=0.05) confirmed this difference, but only with * (p-value=0.0105). (Massive rock vs Interbeds/laminate p-value=0.3346, Interbeds/laminate vs Weathering p-value=0.0621.)

Weathering conditions' prolific fossil count could have occurred simply because weathering exposes more fossils to the surface for counting (figure 1). Another possible factor could be the way interbeds/laminate and massive rock are formed. As interbeds and laminate occur in calm and regular depositional environments, they might be more likely to sweep fossils under their bricklike layers rather than expose them to the surface [14]. Massive rock, assuming it is caused by the depositional environment, indicates a large amount of sediment was deposited at one time, most likely due to an intense storm or other natural disaster. Such an event would quickly bury fossils in a disorganized fashion that is unlikely to reveal many fossils [8] and may be responsible for surface fossil displacement yielding massive rock's significant difference in length as opposed to all other comparisons (figure 2). Weathering conditions may have subjected fossils to less fragmenting force than other conditions—particularly, massive rock.

There were some cases in which interbeds/laminate were also present in square meters of weathering. There could therefore be an interaction between the rock itself weathering away and revealing larger, more intact fossils and the weathered rock obscuring other depositional patterns at play. This indicates why the number of fossils per square meter in weathered rock conditions was not significantly different when compared to interbeds/laminate. Locations 1 and 3 both belong to the Catheys formation, whereas the outcrop at Location 2—which contained the most fossils—belongs to the Hermitage formation [14]. The younger rocks of the Catheys formation corresponding with fewer fossils might indicate the decline of Ordovician organisms in the latter half of the time period, and/or reflect the disorganized tendencies of the Catheys formation when compared to the Hermitage formation, which might displace more fossils from counting.

Limitations and future directions.

Expensive equipment would be required to analyze higher than the bottom square meter of any given outcrop. Additionally, by their nature as cuts—artificial outcrops created by blasting/otherwise removing hills in the way of roads and other developments—these outcrops have incurred some damage that could affect surface fossils. Finally, as ImageJ is susceptible to some user error, future studies should measure an individual fossil several times in order to allow for a statistical analysis of how accurately fossils are being measured by a given user.

Based on these results, there are several interesting factors paleontologists seeking to understand and make paleobiological conclusions based off of the fossil record should consider going forward. Apart from suggesting an increased focus on weathered areas as a possible strategy for researchers to locate more and larger Ordovician fossils, and considering massive rock's potential to fragment fossils, this data suggests holes in the fossil record in areas with rock conditions that are massive and/or contain interbeds/laminate. This is relevant not only to sample collection, but to analysis, as the environments typical of rock conditions with interbeds/laminate and massive rock—deep, calm waters and periods of tumultuous storms, respectively—might have more underrepresented species than previously thought.

Particularly interesting in this dataset is the short/weathered section of Location 2. Apart from having the highest fossil counts of any section in any outcrop (sometimes by hundreds of fossils), it contained the most complete fossils of any section, although most of these fossils were small (less than 0.3 cm on average) compared to fossils in other locations (most of which were at least a centimeter on average). Since complete vs fragmented fossils were not recorded, there is no statistical analysis to strengthen this observation, but it still relates to the phenomena of lithification bias. Typically, lithification bias posits that smaller organisms are more likely to be fragmented under geologic pressures over time, and thus the fossil record is biased to represent larger organisms [10]. This study, and in particular this section of six square meters, counters that notion: larger fossils might have been more likely to be fragmented over time, where smaller fossils were more likely to remain intact and complete. Granted, lithification bias is known to operate differently on certain fossils based on surface area, their original material, and other factors in addition to size, but further research on this point—particularly research which would include counts of complete and fragmented fossils—could lead to a better understanding of how lithification bias affects invertebrates, and particularly shell fossils, differently than vertebrate species.

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REFERENCES.

1. National Geographic Society, Paleontology. (2011).
2. DarrochLab, Projects. (2021).
3. D. Jablonski, N. H. Shubin, The future of the fossil record: paleontology in the 21st century, *Proc. Natl. Acad. Sci. U.S.A.* ***112***, 4852–4858, (2015).
4. D. A. Fordham et al., Using paleo-archives to safeguard biodiversity under climate change. *Science* ***369***, 6507, (2020).
5. G. L. Wingard, C. E. Bernhardt, A. H. Wachnicka, The role of paleoecology in restoration and resource management—the past as a guide to future decision-making: review and example from the greater everglades ecosystem, U.S.A. *Fron. Ecology Evo.* ***5***, 11, (2017).
6. M. L. Droser, S. Finnegan, Ordovician radiation: a follow-up to the Cambrian explosion? *Integ. Comp. Bio.* ***43***, 1, (2003).
7. H. L. Kempf et al., Comparisons of late Ordovician ecosystem dynamics before and after the Richmondian invasion reveal consequences of invasive species in benthic marine paleocommunities. *Paleobio.* ***46***, 3, (2020).
8. M. E. Patzkowsky, S. M. Holland, *Stratigraphic Paleobiology: Understanding the Distribution of Fossil Taxa in Time and Space* (UChicago Press, Chicago, IL 2012).
9. A.K. Behrensmeyer, Behrensmeyer—bones of Amboseli. *[Smithsonian]*
10. A. D. Hawkins, M. Kowalewski and S. Xiao, Breaking down the lithification bias: the effect of preferential sampling of larger specimens on the estimate of species richness, evenness, and average specimen size. *Paleobio.* ***44***, 2, (2018).
11. M. E. Patzkowsky and S. M. Holland, The stratigraphic distribution of fossils in a tropical carbonate succession: Ordovician Bighorn Dolomite, Wyoming, USA. *PALAIOS* ***24***, 5/6, (2009).
12. S. M. Holland and M. E. Patzkowsky, Sequence stratigraphy and relative sea-level history of the middle and upper Ordovician of the Nashville dome, Tennessee. *J. Sediment. Res.* ***68***, 4, (1998).
13. B. F. Dattilo et al., Fossils and stratigraphy of the upper Ordovician standard in south eastern Indiana (Indiana University, Purdue University Fort Wayne, IN 2013).
14. DBPedia, About: Interbedding.
15. Summer, Dawn, Geoscience LibreTexts, 9.7: Sedimentary Facies. (University of California, CA 2020)
16. Britannica, Lamina | Geology.
17. Open Geology, Facies – Historical Geology.
18. National Institutes of Health (NIH), ImageJ. https://www.nih.gov/

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