Can fossil fragments help determine biodiversity in an ancient ecosystem? An analysis of Devonian crinoid stems from upstate NY

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Abstract

Our study explores fossilized crinoid stem fragments (called columnals) from a previously undescribed Devonian outcrop in upstate New York to determine the range of variation present and whether this variation is reflective of species biodiversity within the group. This will allow us to establish what kinds of questions can be asked and answered about extinct crinoids and their ecosystems when only the stem fragments are preserved.

Our initial analysis revealed a bimodal distribution in the size (diameter) of crinoid columnals. Other features such as the shape, number of articular ridges, or proportions of the columnals did not demonstrate any particular pattern of variation. We hypothesized that the difference in diameter might indicate the presence of two taxonomic groups (such as two different species). Alternatively, the difference could indicate two types of columnals within a single species. To differentiate between these alternatives, we looked for specimens in which the columnals have not separated. The few such specimens we found consisted of alternating nodal and internodal columnals, but there was very little size difference between the two types of columnals. Therefore, we drew the tentative conclusion that the bimodal distribution of columnals represents two taxonomic groups.

Our research contributes to the field by highlighting the potential of crinoid columnals to serve as indicators of crinoid biodiversity. Since crinoid fossils mainly consist of stalks and columnals, such an approach would allow researchers to make use of a vast, previously underutilized source of paleontological data.

Introduction

- Crinoids: a class of echinoderms related to sea stars and sea urchins
- Common fossils, but usually found as disarticulated columnals (stem components; see Figure 1)
- Can these fragments be useful for estimating crinoid biodiversity?

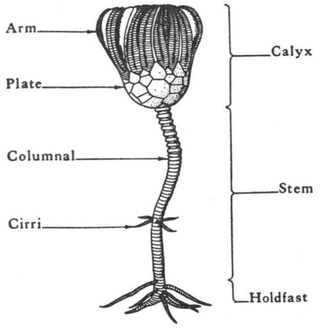


Figure 1: Crinoid anatomy. Columnals are the individual disks that make up the stem. Image from fossil-facts-and-finds.com

A

Figure 2: Fossil locality in Vestal, NY. A: Red star marks the location of the town of Vestal. Image from Wikimedia Commons. B: Choconut Creek. Image from YouTube channel of MrHeli4444, still from video "Choconut Creek, Vestal NY"

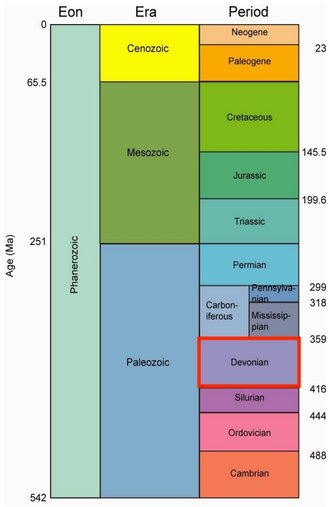


Figure 3: Geological time scale, with the Devonian period outlined in red Image modified from geologypage.com

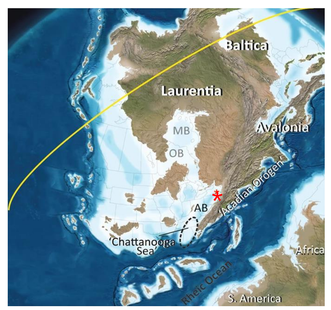


Figure 4: Paleogeographic map of North America during the late Devonian period. The yellow curve represents the equator, and the small red star near the center indicates our fossil locality. Image from Lu et al 2019 https://www.nature.com/articles/s41598-019-43993-y

Materials and methods

- Materials: Shale storm deposit slabs from Choconut Creek in Vestal, NY (Figure 2a, 2b)
- Age: late Devonian (382-372 million years ago; Figure 3)
- Paleoenvironment: NY state was a shallow subtropical ocean (Figure 4)
- Measured the size (diameter) and shape (ratio of diameter to lumen) of 97 crinoid columnals preserved as impressions in five shale slabs (Figure 5)
- Statistical analysis to identify patterns of variation: distribution, skewness, bimodality, and correlation

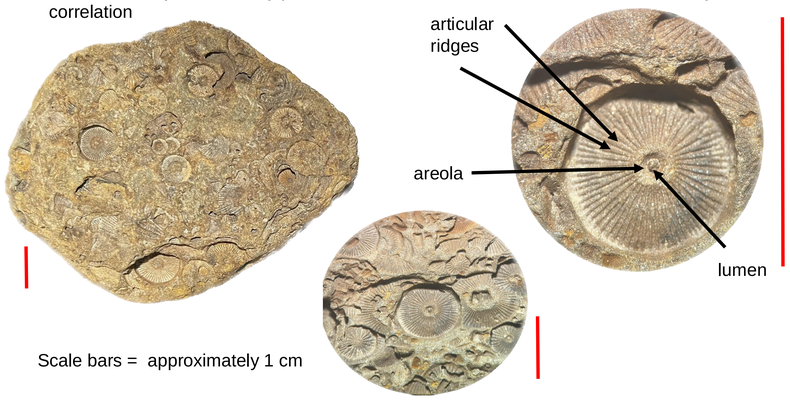


Figure 5: Crinoid columnals in shale samples from Choconut Creek in Vestal, NY. Photo credit: Marawon Elsayed

Results

- Columnal size has a clear bimodal distribution, demonstrated in three different size variables (columnal diameter – Fig 6A, areolar diameter – Fig 6B, and luminal diameter – Fig 6C)
- Columnal shape (proportions) is/are only possible to measure in a small sample of columnals, resulting in potentially unreliable interpretations
- The size (diameter) of the columnals is strongly correlated with the number of articular ridges (radiating lines; Figure 6D)

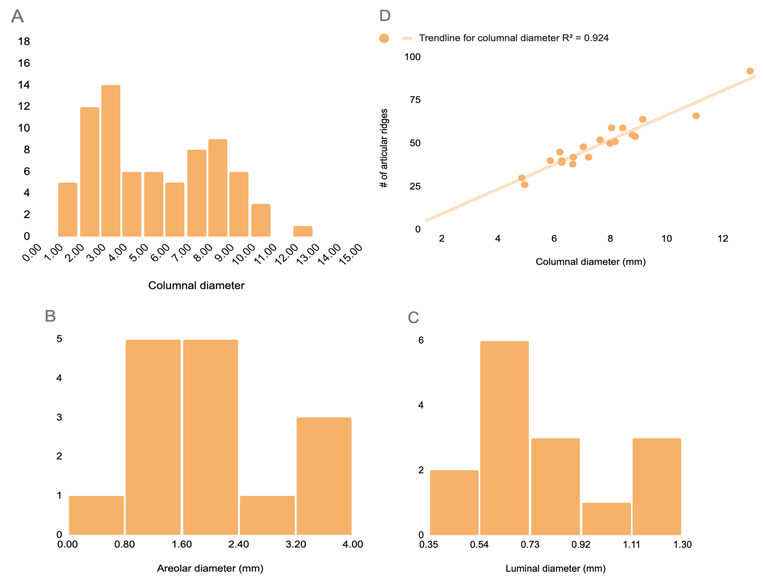


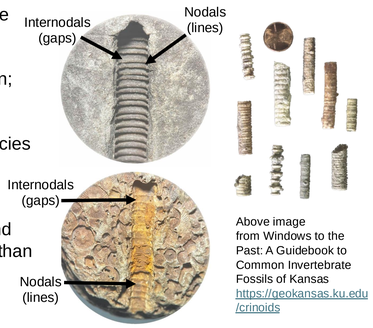
Figure 6: Graphs depicting the distribution of columnal size data (A, B, and C) and the correlation between size and number of articular ridges (D).

Acknowledgements

We are grateful to Bushra Hussaini at the American Museum of Natural History for access to the fossil crinoid collections, and to Sarah Sheffield of Binghamton University for brainstorming research questions with us. We are also grateful to the CUNY Research Scholars Program (including and especially program director Farshad Tamari and program administrator Frances Samuel) for their support of this project.

Discussion and interpretation

- Biomodality in columnal size suggests one of three interpretations
  1) Two taxonomic groups (interspecies variation; Fig 7)
  2) Two growth stages of one taxonomic group
  3) Two alternating types of columnals (intraspecies variation—nodals and internodals; Figure 7)
- Columnals representing two growth stages is unlikely, since columnals increase gradually and continuously in size within a single stalk (rather than as discrete size classes; see Figure 7)
- While alternating types of columnals (nodals and internodals) are present in these specimens, the two types are only slightly different in average diameter (0.4 mm). Therefore, the large difference (4 mm) in diameter of the full sample of columnals is unlikely due to nodal vs internodal differences in diameter
- Therefore, we interpret the bimodality as reflective of two taxonomic groups of crinoids represented in our sample



Above image from Windows to the Past: A Guidebook to Common Invertebrate Fossils of Kansas https://geokansas.ku.edu/crinoids

Figure 7: Two left images are stalk fragments from our specimens with multiple, articulated columnals, showing minimal variation in columnal diameter. Right image displays stalk segments from various other crinoid species, demonstrating that variation in columnals may be due to either intraspecies or interspecies variation.

Conclusions

- Statistical analysis of disarticulated crinoid columnals can reveal biodiversity
- This approach can help researchers make use a previously underutilized source of data about ancient ecosystems

Using AI in research

As part of this project, we explored the use of AI at each step of the process (we used ChatGPT 4.0). Along the way, we evaluated the utility and appropriateness of using AI. Here is a summary of the process and our conclusions:

Background information: AI did a fairly good job explaining background information related to our project, such as defining scientific terms and summarizing the anatomy, physiology, and fossil record of our study organisms. The tool was really helpful to quickly define terms in various ways to facilitate understanding them in context.

Literature review: AI based on large language models (LLMs) is currently not very effective at identifying published research on a given topic, nor at filtering that research for relevance or significance.

Formulating potential research questions: We used AI to brainstorm possible research questions. The tool was very useful for coming up with a pool of reasonable questions, though it was unable to sort through them to decide which ones were feasible for our specific dataset, budget, and research timeline
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Data analysis: ChatGPT 4.0 can use several widely available, free plug-ins for statistical analysis (and other features). We found that this tool worked extremely well. Users upload a spreadsheet, which the program first describes. This allows users to see whether the program correctly understands the spreadsheet, and correct any misunderstandings before proceeding. Users can then ask AI in plain English what statistical tests are appropriate to determine various relationships or patterns within the data. The tool explains the assumptions of each statistical model, and can modify explanations easily as well as test the assumptions of the model. It also explains under what circumstances each test can be used, and can help to interpret the results once calculated. Some basic understanding of statistics is necessary, but using AI greatly expedites the task of figuring out what test to use and how to employ it, the way you have to with traditional statistical software. The tool also produces graphs, although it's not easy to export or share those.

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