Observing Internal Enigmatic Rock Structures from the Terminal Ediacaran of Namibia

Gracie M. Bixler, Katherine Turk, Simon A. F. Darroch

Department of Earth and Environmental Science, Vanderbilt University, Nashville, Tennessee, USA, 37235

KEYWORDS. Ediacaran, Cambrian, Burrowing, CT Imaging

BRIEFS. The study of an Ediacaran rock slab to determine if burrowing occurred in the late-Ediacaran.

ABSTRACT. Burrowing is a complex adaptation that was not seen until the Cambrian time period (540 Mya). The presence of burrowing in an earlier time could help to understand the world at that time and potentially why the Cambrian Explosion occurred. Using rock samples collected in Namibia from the late-Ediacaran, we perform an analysis through 3D imaging, reconstruction, and segmentation to determine if the internal structures are the result of burrowing. After segmentation, we visually analyzed the features and details of these structures. Overall, features such as spiraling and branching were consistent across the slab. The samples were also compared to past research on gas escape structures in which the structures were different. This difference indicates a strong case that these structures are not gas related but are biological.

INTRODUCTION.

The Ediacaran time period occurred around 600 million years ago (Mya). Due to the small amounts of oxygen, life on the sea floor was simple and mostly stationary. Behaviors such as swimming, hunting, and burrowing were too complex for the organisms at the time. Many hypotheses discuss these organisms living an anaerobic lifestyle [1]. Fossils of petalomamids have been found in the Ediacaran geological layer of earth. Typical to the time, petalomamids were organisms known to be benthic and motionless. In the Cambrian time period (540 Mya), the Cambrian explosion took place in which complex life emerged. Through the Cambrian explosion, ecological features such as the relationship between predator and prey as well as adaptations like burrowing became more prevalent. Many researchers debate why the Cambrian explosion occurred, but a popular belief is that the presence and fluctuation of oxygen and carbon created a new environment for these organisms to live. Processes like anaerobic lifestyles could be replaced with aerobic lifestyles and thus leading to more mobility [2].

Burrowing is the process of creating tunnels within the sediment for dwelling or food purposes. Burrowing is an adaptation that the geological community has only seen in the Cambrian period. It is an action that has complex motion in which an organism needs to have advanced adaptations. The act of burrowing even has complex effects on its environment due to its separation of the sediment. Because burrowing is a downward motion, it would bring new nutrients to a level of the sediment that has not been exposed. A Cambrian aquatic worm, Priapulida, is known for its presence of vertical burrowing [3]. To date, there is no evidence of vertical burrowing in the Ediacaran, however, it is thought to be possible.

Computed Tomography (CT) scanners are X-Ray machines that allow for a 3D visual of an object's interior. Using CT scanners on rocks gives insight of what is inside without destroying the external structure of the sample. CT scans are a digital record that allow for research to continuously be done [4].

Using rock samples collected in Namibia Africa, our goal is to use 3D imaging to look for evidence of burrowing in soft sediment. The main question in this study is: Does this rock sample show us evidence of vertical movement in the late Ediacaran? The purpose of this study is to determine if there was vertical movement in the late Ediacaran as well as to compare these enigmatic structures to non-biological structures. Based off the dotted pattern and texture of the exterior of each sample, I hypothesize that these rock samples show evidence of burrowing in the late Ediacaran.

MATERIALS AND METHODS.

Geological Setting and Sample Collection.

Limestone/sandstone samples were collected from Camp Koelkrans in Southern Namibia (Figure 1). Camp Koelkrans is in the Witputs Subbasin, and it preserves the Spitskop Member, Urusis Formation, Nama Group. Rock samples were collected along the base of a cliff in Camp Koelkrans which once was the sea floor of the Ediacaran. These samples were taken to the United States and studied in the laboratory at Vanderbilt University [5].

CT Scanning.

The rock samples that were previously collected were cut into smaller samples (6 individual samples). These cut rocks were secured with double sided tape onto Styrofoam blocks to maintain stability but without interfering the pictures taken. The samples were placed in the center of the CT Scanner (NSI ImagiX micro-CT instrument). The sample and stage were moved up and down to ensure the sample was as centered as possible. If a sample is not centered, it creates artifact rings that interfere with the view of the internal structures. After the sample is set, settings for each sample must be changed. Because each sample has different coloring and thickness, the light and camera settings need to be changed to ensure the best pictures. Around 800 pictures were taken per sample and each scan took around 1-2 hours [4].

Reconstruction.

Using the NSI software, each sample was reconstructed. Reconstruction is the process of assembling each individual CT photo and compiling them into one 3D model. This process helps to get a proper view of the interior of the rock structure. After the sample was reconstructed, the sample was edited for the clearest image of the details in

Figure 1. Koelkrans Slab Piece. An example of the sampled rocks. Piece one that was cut from the Koelkrans slab.

the structure. The different types of sediment present within the rock had to be either lightened or darkened to be able to see the structures. The CT scan takes pictures of the air around the sample, so in reconstruction, the pictures of air had to be cut and removed from the sample. After a reconstruction was complete, they were studied to ensure that no ring artifacts were present. If a ring artifact occurred, the CT scan was performed again.

Segmenting.

VGSTUDIO MAX was used to isolate and segment structures within the samples. Each reconstructed picture was run through VGSTUDIO MAX. If the sample had dark spots, it was outlined and highlighted. Each new structure was given a different color to help distinguish the shape and presence of the different structures. While working with this software, each layer of the reconstructed picture was scrolled through to find and isolate all structures. Segmenting was completed for all six samples that were scanned and reconstructed.

Visual Analysis.

After scanning, reconstruction, and segmenting was completed, visual analysis was performed to observe and identify the structures. Features such as shape, direction, thickness, depth, etc. were observed and noted. These visual analyses were compared to past research to finalize the analysis.

RESULTS.

Through visual analysis of the segmented samples, structures were found. These structures composed of unique shapes that branch out and have frequent curves. Some structures contained branching, spiraling and vertical and horizontal components. Other structures contained branching but no spiraling. A few structures contained U-shape patterns.

Image A in Figure 2 shows the structures found in piece one of the Koelkrans slab. The light blue, green and red structures represent some vertical and slightly horizonal structures. The blue structure is spiraling, branching, and showing vertical and horizontal structures.

Image B in Figure 2 shows the second piece of the slab. This piece holds thirteen structures that exemplify many different features. Throughout this slab there are many exemplar structures. The muted green and yellow structures show U-Shaped segments. The purple structure shows a spiral structure, and the blue structure demonstrates branching.

Image C in Figure 2 shows the six structures of piece six. The light blue structure is a great example of branching and horizontal and vertical features. This structure shows slight spiraling at the top, but overall does not feature spirals. The other structures in this sample are simple since they are only horizontal and not very long. Most are only horizontal, and some are not very long and therefore show simple structural features.

DISCUSSION.

A past study on an Ediacaran rock sample found vertical structures however, they were not burrow structures but rather gas escape structures [6]. Overtime as sediment is compressed,

gas gets trapped within the layers, as the gas escapes it leaves behind these structures that are not biological. These gas escape structures are therefore not trace fossils and do not show evidence of burrowing [6].

While comparing the gas escape structures to those found in the Koelkrans slab, many differences were identified. The branching and spiraling features that are present in the Koelkrans slab is significantly different than that of gas structures in that gas travels upward and not typically in spiral motions. The structural differences between the gas escape structures and the Koelkrans structures show that the Koelkrans

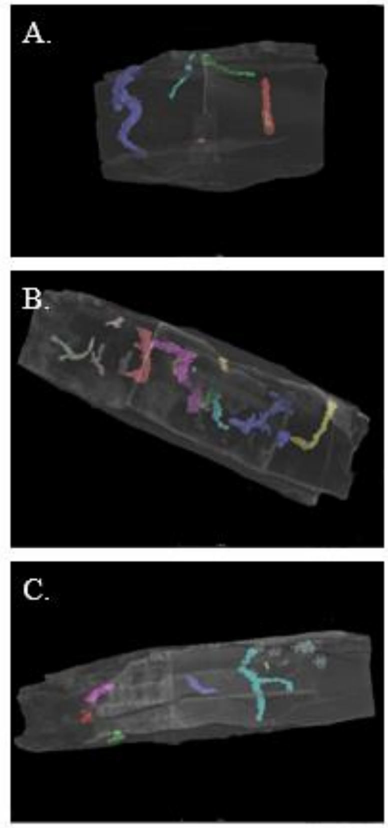

Figure 2. Internal Structures in Three Slab Pieces. The top piece (A) is piece one of Koelkrans slab, showing five structures. The middle piece (B) is piece two of Koelkrans slab, showing thirteen structures. The bottom piece (C) is piece six of Koelkrans slab, showing six structures.

structures are most likely biological due to their complex multi-directional shapes. The understanding of gas escape structures helps the understanding of why sediment structures can be present in the Ediacaran time period. The presence of gas escape structures thus helps to corroborate the hypotheses of stationary anerobic lifestyles. However, the presence of the complex multi-directional shapes found in the Koelkrans samples can change the understanding of life in the Ediacaran and can disprove the hypotheses made based on this time.

From the visual analysis data and segmentations that were completed, there is strong evidence that these structures could be biological. In particular, the complexity of paths in these samples show that whatever was escaping was also moving (as evidenced by L- and U-shaped structures in the block). Present day worms such as *Sipunculida* burrow in parallel, U-Shape, spiraling patterns [7]. When comparing their burrow patterns to the Ediacaran structures they show similar features and features particularly different than that of the gas escape structures.

A potential next step to this study would be to gather quantifiable data of the structures from the samples already collected. For example, a volumetric analysis of the internal structures identified in this study could be conducted, including measuring structure width, depth, and height. These values would then be compared with published examples of gas escape structures and biological structures from the literature. These volumes can be measured by using volume Computed Tomography [8]. These comparisons might further support the identification of biological structures in the Koelkrans slab.

Aquatic worms release mucus membranes along their burrows. Chemically testing the identified structures in the Koelkrans samples for stable isotopes could give us a better idea of what these structures are.

The presence of higher-than-expected stable carbon isotopes in can be an indicator of biological matter [9].

SUMMARY.

Based on the CT Scans, digital segmenting and reconstruction, enigmatic structures were found. These structures when analyzed by shape, structure, and direction and compared to present day worm (*Sipunculida)* structures, and gas escape structures found in the Ediacaran. Similar to *Sipunculida* the Koelkrans structures were found to be spiraling, and L and U-shaped. Because these structures are complex and multidirectional, they are shown to be different than the gas escape structures found in similar slabs. Overall, the results of this study suggest that biological features, such as worm burrows, can be identified in the Koelkrans samples from the Ediacaran.

ACKNOWLEDGMENTS.

The work was supported by the Collaborative for STEM Education and Outreach, Research Experience for High School Students (REHSS), and the Department of Earth and Environmental Science. The author would like to thank Dr. Simon A. F. Darroch and Katherine Turk for their guidance and enthusiasm for the Research as well as Dr. Nathaniel Freymeyer, Dr. Kiara Vann and Dr. Taurean Brown for their work to make REHSS possible.

REFERENCES

1. L. B. Cherry et al., A diverse Ediacara assemblage survived under low-oxygen conditions. *Nature Communications*. **13**, 7306 (2022).
2. T. He et al., Possible links between extreme oxygen perturbations and the Cambrian Radiation Of Animals. *Nature Geoscience*. **12**, 468–474 (2019).
3. G. Kesidis, B. J. Slater, S. Jensen, G. E. Budd, Caught in the act: Priapulid Burrowers in early Cambrian substrates. *Proceedings of the Royal Society B: Biological Sciences*. **286**, 20182505 (2019).
4. R. Racicot, Fossil secrets revealed: X-ray CT scanning and applications in paleontology. *The Paleontological Society Papers.* **22**, 21–38 (2016).
5. S. A. F. Darroch et al., The trace fossil record of the Nama Group, Namibia: Exploring the terminal Ediacaran roots of the Cambrian explosion. *Earth-Science Reviews*. **212**, 103435 (2021).
6. L. R. Menon, D. McIlroy, A. G. Liu, M. D. Brasier, The dynamic influence of microbial mats on sediments: Fluid Escape and pseudofossil formation in the Ediacaran Longmyndian Supergroup, UK. *Journal of the Geological Society*. **173**, 177–185 (2016).
7. X. Shen, X. Ma, J. Ren, F. Zhao, A close phylogenetic relationship between Sipuncula and Annelida evidenced from the complete mitochondrial genome sequence of Phascolosoma esculenta. *BMC Genomics*. **10**, 136 (2009).
8. Haba, T., Koyama, S., Kinomura, Y., Ida, Y., & Kobayashi, Influence of 320-detector-row volume scanning and AAPM Report 111 CT dosimetry metrics on size-specific dose estimate: A Monte Carlo Study. *Australasian Physical & Engineering Sciences in Medicine*, **39(3)**, 697–703, (2016).
9. Kocsis, L., Dulai, A., Cipriani, A., Vennemann, T., & Yunsi, Geochemistry of recent and fossil brachiopod calcite of Megathiris detruncata (Terebratulida, Megathyrididae): A modern baseline study to trace past environmental conditions. *Chemical Geology*, **533**, 119335, (2020).

Grace Bixler is a student at John Overton High School in Nashville, TN; she participated in a research internship through the Research Experience for High School Students program at Vanderbilt University.