Quantitative insights into stromatolite morphogenesis: a multi-scale approach to probing paleoenvironmental and biological archives

A. Anders Larson Tevis, Meghan E. King, Akshay K. Mehra
Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195

Introduction

- Stromatolites are **laminated accretionary growth structures** that form away from an original surface of initiation[1-3].
- These sedimentary features are interpreted as recordings of **microbial activity** and **abiotic factors** (e.g., hydrodynamics, seawater chemistry, etc.)[4-5].
- Here, we develop a method to describe the **micro-scale morphological features** of stromatolites using a set of simple **image processing techniques**.
- We implement this tool for the stromatolites of the 1.9 billion year old Pethei Group in Northwest Territories, Canada in order to **reconstruct the paleoenvironmental and biological conditions** of this ancient reef system.

Quantitative stromatolitology

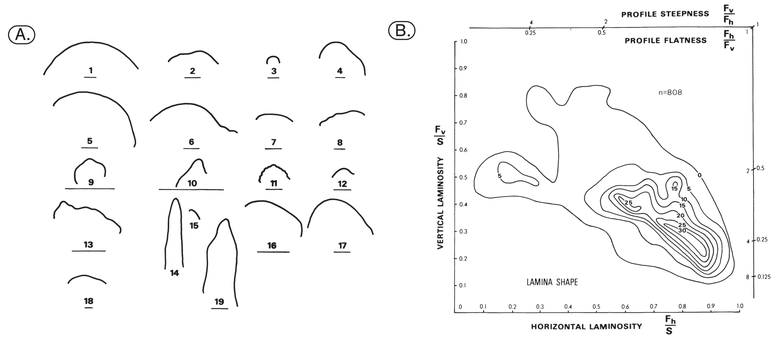


Figure 1. Plates from Yun and Hofmann, 1982. *(a)* Tracings of stromatolite laminations. *(b)* Clustering of stromatolite morphologies based on laminae features.

- Attempts to **quantitatively characterize stromatolite morphologies** date back to 1982[6], but efforts to understand these structures remain **nascent**[7-8].
- **Image processing** techniques enable the extraction of meaningful information from textures to describe morphological features[9-11].

Geologic setting

- The Pethei Group is a Paleoproterozoic (1.88 Ga) carbonate platform with a variety of **shallow marine reef systems**[12-14].
- The Taltheilei, Hearne, and Wildbreade Formations within the Pethei Group contain **diverse organosedimentary structures** deposited coeval, some built by microbial activity[15].

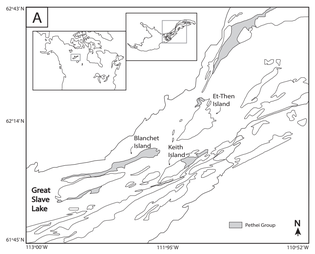
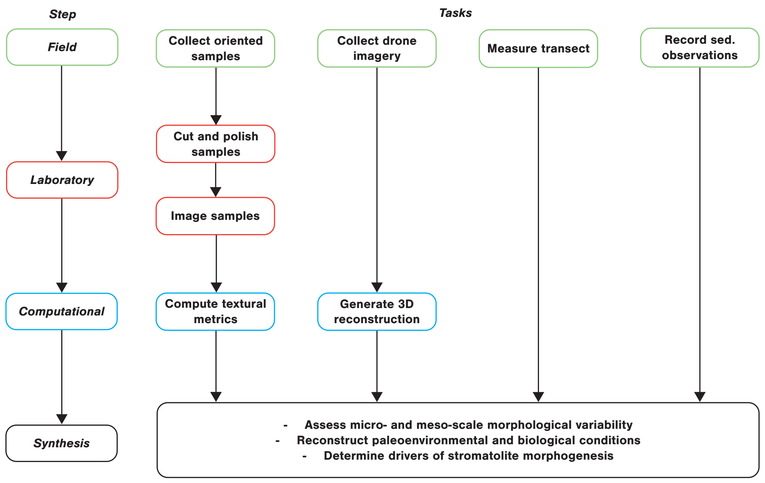


Figure 2. Map of East Arm of Great Slave Lake, Northwest Territories, Canada.

Methods

Figure 3. Flowchart for quantitative assessment of micro- and meso-scale morphological features.



Microbial morphological index

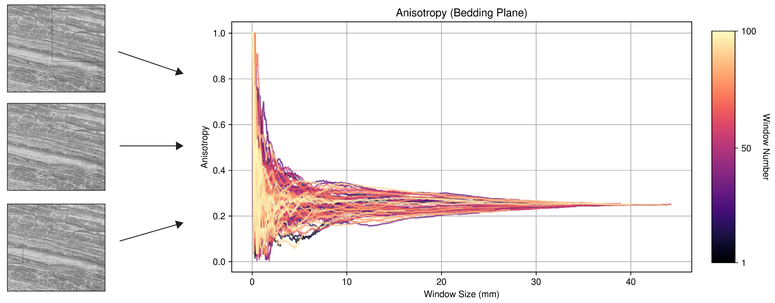


Figure 4. Random seeding of 100 feature windows with pixel-by-pixel increase in window size (for anisotropy).

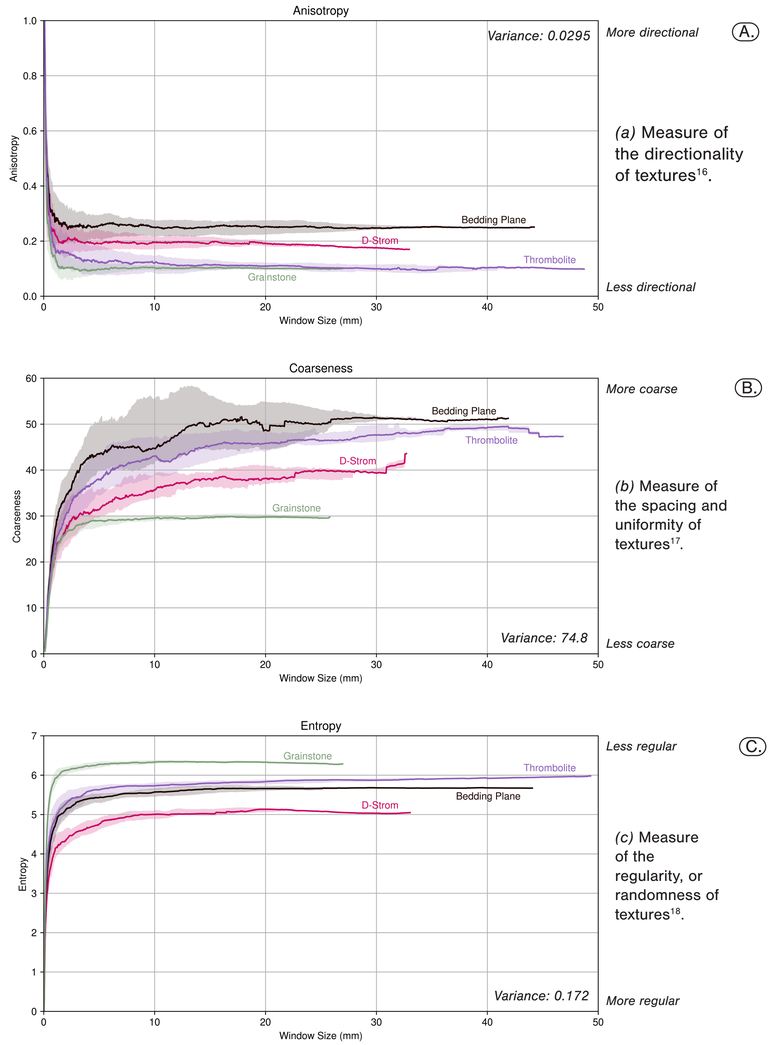
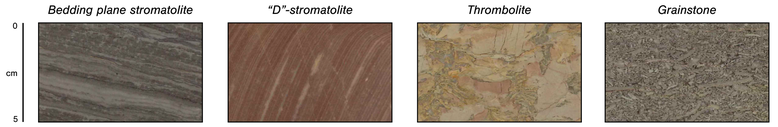


Figure 5. Results of random window seeding and step-wise increase in window size for each textural feature for four representative sample types: bedding plane stromatolite, "D"-stromatolite, thrombolite, and grainstone. Upper and lower bounds are 75th and 25th percentiles, respectively.

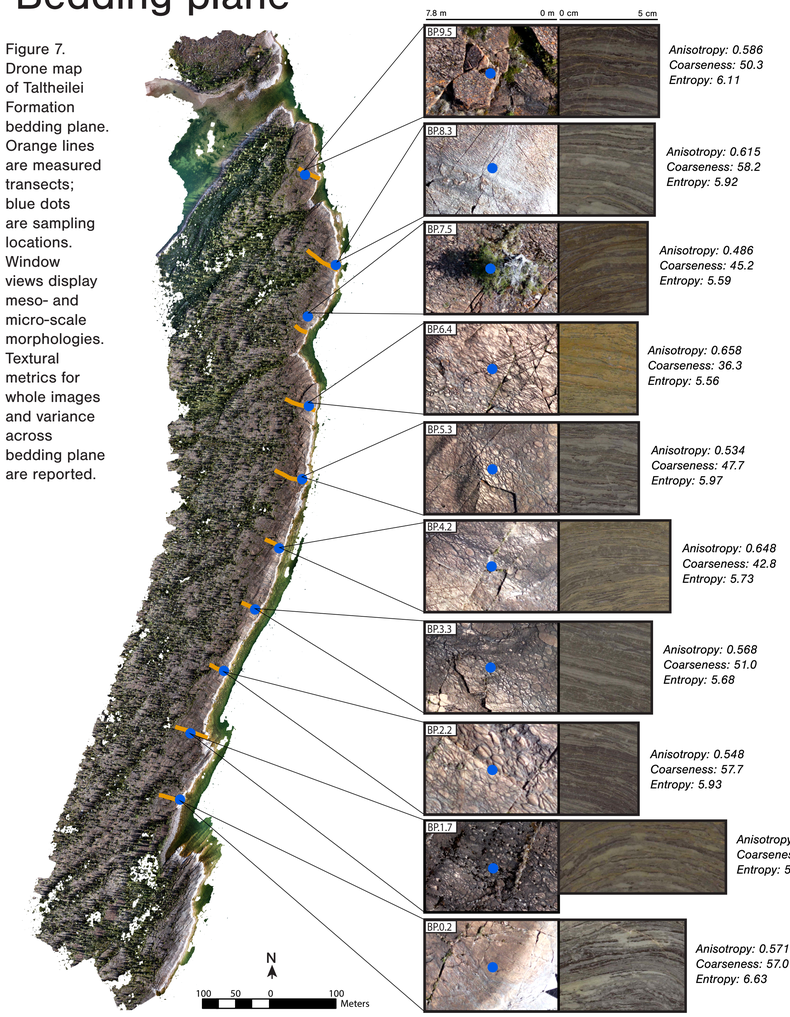


	Bedding plane stromatolite	"D"-stromatolite	Thrombolite	Grainstone
Anisotropy:	**0.568**	**0.336**	**0.121**	**0.186**
Coarseness:	**51.0**	**41.7**	**50.8**	**29.8**
Entropy:	**5.68**	**5.19**	**5.98**	**6.32**

Figure 6. Images of polished slabs for representative sample types. Results of textural classification for largest window size (whole image) for each sample are reported.

Bedding plane

Figure 7. Drone map of Taltheilei Formation bedding plane. Orange lines are measured transects; blue dots are sampling locations. Window views display meso- and micro-scale morphologies. Textural metrics for whole images and variance across bedding plane are reported.



Variance — Anisotropy: 0.00309; Coarseness: 47.9; Entropy: 0.101

Conclusions and future work

- Anisotropy, coarseness, and entropy **differentiate textures intuitively.**
- Bedding plane stromatolites exhibit **consistent micro-scale morphological features**. Variance across bedding plane is small relative to standards (9.6, 1.6, and 1.7 times smaller for anisotropy, coarseness, and entropy, respectively).
- Micro-scale textural features **do not** appear to be influenced by variations in gross stromatolite morphology.
- Microbial activity may have been **relatively uniform** across this ancient reef system and **paleoenvironmental forcings** (e.g., proximity to channel, etc.) **likely drove meso-scale stromatolite morphogenesis.**
- Create facies map of bedding plane to **quantitatively assess meso-scale morphological features.** Test additional textural feature descriptors.
- **Publish** this work (and references within) and create an **easily accessible textural analysis tool and database**.

References

Contact: tevisaa@uw.edu

[1] Kalkowsky, V. H. E. Z. (1908). Deutsch. Geologischen Gesellschaft 60, 68-125. [2] Walter, M. R. (1976). Elsevier, Amsterdam. [3] Semikhatov, M. A. et al. (1979). Can. J. Earth Sci., 16(5), 992-1015. [4] Awramik, S. M. et al. (1976). In Developments in Sedimentology (Vol. 20, pp. 149-162). Elsevier. [5] Grotzinger, J. P., & Rothman, D. H. (1996). Nature, 383(6599), 423-425. [6] Yun, Z., & Hofmann, H. J. (1982). J. Geol., 90(3), 253-268. [7] Grotzinger, J. P., & Knoll, A. H. (1999). Annu. Rev. Earth Planet Sci., 27(1), Article 1. [8] Bosak, T. et al. (2013). Annu. Rev. Earth Planet Sci., 41, 21-44. [9] Corsetti, F. A., & Storrie-Lombardi, M. C. (2003). Astrobiology, 3(4), 649-655. [10] Storrie-Lombardi, M. C. et al. (2004). Chaos Solit. Fractals, 20(1), 139-144. [11] Wagstaff, K. L., & Corsetti, F. A. (2010). Astrobiology, 10(4), 363-379. [12] Hoffman, P. F. (1968). Geological Survey of Canada, Paper 68-42, 93. [13] Sami, T. T., & James, N. P. (1993). Sedimentology, 40(3), 403-430. [14] Sami, T. T., & James, N. P. (1994). J. Sediment. Res., 64(2b), 111-131. [15] Pope, M. C., & Grotzinger, J. P. (2000). In Carbonate Sedimentation and Diagenesis in the Evolving Precambrian World (Vol. 67). [16] Manzuk, personal correspondence. [17] Amadasun, M., & King, R. (1989). IEEE Trans. Syst. Man Cybern. Syst., 19(5), 1264-1274. [18] Shannon, C. E. (1948). Bell Syst. Tech. J., 27(3), 379-423.

Acknowledgements

- The authors would like to thank the Mary Gates Endowment for Students for supporting this work.