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Detecting signature of life on terrestrial and Martian rocks

Contribution of microbial mats in the biogeomorphological responses of desiccated sediments

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Introduction

Slide 1 Good afternoon, everyone, my name is Liza Alexandra Fernandez, and I am a PhD student at the University of Clermont Auvergne and the University of Toulouse, working in collaboration with MAD-Environnement and the University of Cambridge. Today, I am presenting my thesis on detecting life signatures in terrestrial and Martian rocks, focusing on the contribution of microbial mats to the biogeomorphological responses of desiccated sediments.

Study context

Slide 2 For several years, space research has been rapidly advancing, especially with the development of remote sensing and imaging tools. This is particularly evident in Martian exploration, where orbiters and rovers collect vast datasets. Among the key scientific questions being addressed, the search for potential traces of life remains very fascinating. (Reference: **1** ©NASA <https://science.nasa.gov>)

Slide 3 Why search for life on Mars? Mars and Earth formed at about the same time and share similar early histories. Ancient Martian environments resembling those on early Earth have been identified, such as lake systems dating back around 3.5 billion years. (References: **2** Mangold *et al.*, 2021; **3** Noffke and Awramik, 2013; **4** Cohen *et al.*, 2013; **5** Kite, 2019; **6** Rapin *et al.*, 2023)

Slide 4 Given this potential, what forms of traces are we looking for? Various biosignatures exist fossilised microorganisms, biologically influenced minerals, chemical or isotopic biomarkers, and biological structures. (References : **7** McMahon *et al.*, 2018 ; **8** Ehlmann *et al.*, 2008; **9** van Zuilen, 2007; **10** ©Dov Corenblit)

Slide 5 This research focuses on biologically influenced sedimentary structures, specifically Microbially Induced Sedimentary Structures (MISS).

Sedimentary Structures: MISS

Slide 6 Defined by Nora Noffke in 1997, MISS are sedimentary structures formed by microbial activity. They belong to a broader group called microbialites, which also includes stromatolites. These microbialites are the oldest known evidence of life on Earth, dating back approximately 3.5 billion years. MISS usually form in intertidal zones at the water-sediment interface, where microbial mats grow. These mats produce extracellular polymeric substances (EPS) that stabilise the surface, altering sediment dynamics and creating these distinct MISS patterns. (References: 3 Noffke and Awramik, 2013; 4 Cohen *et al.*, 2013; 5 Kite, 2019; 6 Rapin *et al.*, 2023; 11 Noffke, 1997; 12 Noffke, 2010)

Slide 7 The diversity of MISS—in terms of environments, morphologies, and biogeological parameter—makes them powerful research tools. However, their variety also raises a challenge: how can we classify all these structures? Several classification methods have been proposed, based on structural and textural traits linked to microbial mat growth and sediment dynamics. (References: 4 Cohen *et al.*, 2013; 5 Kite, 2019; 6 Rapin *et al.*, 2023; 10 © Dov Corenblit; 12 Noffke, 2010; 13 Noffke, 2021; 14 Davies *et al.*, 2016)

Slide 8 But, identifying biosignatures in fossilised terrestrial or extraterrestrial material requires distinguishing clearly between biogenic and non-biogenic features. (References: 15 © Dov Corenblit; 14 Davies *et al.*, 2016)

Slide 9 This is especially difficult as some structures may arise from both biological and geological processes—this is a core issue in the present study.

Research Question

Slide 10 We focus on a specific type of MISS that forms in drying environments: mat-cracks and their abiotic counterparts, desiccation-cracks. This focus is shaped by the constraints of a three-year PhD, the widespread presence of these structures in both fossil and modern records, their reproducibility in lab settings, and the presence of potential Martian analogues. (References: 6 Rapin *et al.*, 2023; (mcam100276); 14 Davies *et al.*, 2016; 15 © Frédéric Azemar; 16 © Joséphine Leflaive)

Slide 11 The aim is to develop an image-based detection system to distinguish between biotic structures (with microbial mats) and abiotic ones (without mats), with potential applications for Martian imaging. The two main objectives are (i) analysing the variability of fossil and modern MISS and (ii) developing an AI-based classification method. (References: 6 Rapin *et al.*, 2023 (mcam100276); 14 Davies *et al.*, 2016; 15 © Frédéric Azemar; 16 © Joséphine Leflaive)

Slide 12 This leads to the central research question: **How to characterise and classify the degree of biogenicity on a surface?**

Dataset

Slide 13 To meet the first objective, we built a representative dataset through fieldwork: fossil MISS in Permian-aged surfaces in the South of France, and modern MISS in Mediterranean coastal ponds. (Reference: **15** © Frédéric Azemar)

Slide 14 We also performed controlled lab experiments to replicate MISS formation under varied conditions, allowing us to isolate key variables. (References: **10** © Dov Corenblit; **16** © Joséphine Leflaive; **17** Corenblit *et al.*, 2023)

Slides 15 For the second objective, we sampled sediment surfaces and microbial mats and used a standardised 3D photogrammetry protocol. (Reference: **15** © Frédéric Azemar; **18** Agisoft Metashape®)

Slides 16 The 3D images were then pre-processed for statistical and AI analysis, and results were compared with expert interpretations.

Analyses

Slide 17 Statistical analysis included digital elevation models using eight geomorphometric raster types. These help identify typical relief patterns and biogeomorphological responses of biotic vs abiotic surfaces. (Reference: **18** Agisoft Metashape®; **19** Jasiewicz and Stepinski, 2013)

Slide 18 For the AI classification, we used convolutional neural networks (CNNs). These networks process information similarly to biological neurons. In image analysis, CNNs simplify data before classifying it. We used supervised learning, where the model is partially guided: a training dataset helps tune the CNN and a test dataset (unseen by the model) evaluates its accuracy. (Reference: **18** Agisoft Metashape®)

Slide 19 Our current CNN achieves around 90% accuracy. Class-activation maps highlight the image regions used for classification. These are compared with human "blind" classifications to assess whether the AI improves detection and precision. (Reference: **18** Agisoft Metashape®)

Slide 20 The project has made significant progress, with key results already published or in development.

Current Work & Perspectives

Slide 21 A relevant publication is Corenblit *et al.* (2023), on CNN-based MISS classification. I also presented our most recent findings at the Astrobiology Science Conference 2024, focusing on structural variability among different biological sources. (Reference: **17** Corenblit *et al.*, 2023; **20** Fernandez *et al.*, 2024)

Slide 22 We have since expanded our field dataset with thousands of new images from the South of France. These will help refine the CNN model and better determine surface biogenicity. (Reference: 15 © Frédéric Azemar)

Slide 23 We are also continuing new lab experiments, currently involving an M1 student intern, to study how geological conditions affect MISS responses in clay-sand mixtures.

Slide 24 At this stage, we are placing more emphasis on the abiotic controls that shape biogeomorphological responses.

Conclusion

Slide 26 This concludes the first phase of my PhD research. I'd be happy to answer any questions, and feel free to contact me if you're interested in following the project.

Slide 27 Thank you very much for your attention!

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Slide 28

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