Hunting for an ancient symbiosis: The present is the key to the past

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Overview

WHAT DO WE STUDY?

- We want to determine a recipe for the formation and preservation of microbial fossils. Specifically, we focus on aggregates formed by anaerobic methane-oxidizing archaea (ANME) and sulfate reducing bacteria (SRB), which form a symbiosis near deep ocean methane seeps, where methane, the source of energy, meets sulfate, the electron acceptor.
- These aggregates influence the formation of methane-derived authigenic carbonates as well as sulfide minerals in deep sea sediments.

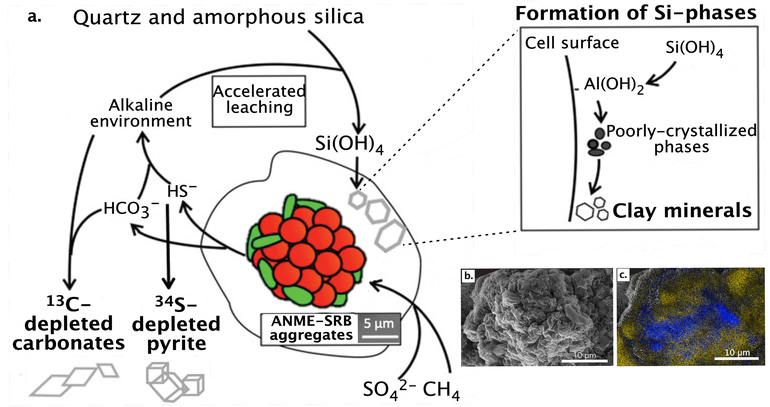
WHERE COULD ANME-SRB AGGREGATES BE PRESERVED?

- The symbiosis between ANME and SRB could go as far back as ~3 billion years.
- We observe how ANME-SRB aggregates biomineralize and get entombed in modern carbonates around active methane seeps, as a proxy for their preservation in ancient carbonates.

WHY DO WE STUDY THEM?

For early Earth (and other planetary bodies if life ever evolved there), the discovery of ANME-SRB aggregates would be critical to understanding the biogeochemistry of the environment, ANME-SRB's relative importance as mineralization agents, and how microbes may be contributing to their own preservation.

Model of ANME-SRB-induced mineral formation



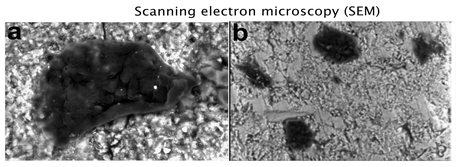
a. The metabolism of ANME-SRB alters the chemistry of their environment (modified from [1]).

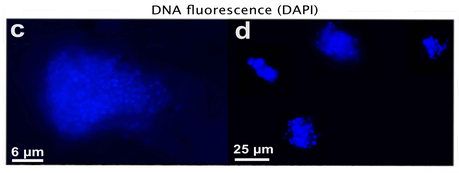
b. SEM image of a modern ANME-SRB aggregate isolated from marine sediments. **c.** Elemental mapping of b. (images from [2]). Yellow: Carbon, Blue: Silicon.

What can we learn from modern ANME-SRB symbiosis (aggregates)?

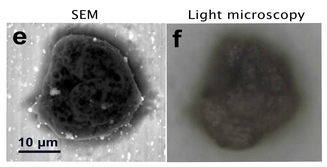
They can be identified in carbonates

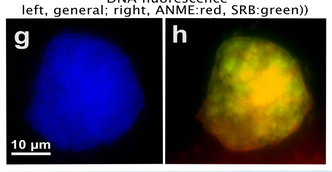
In situ





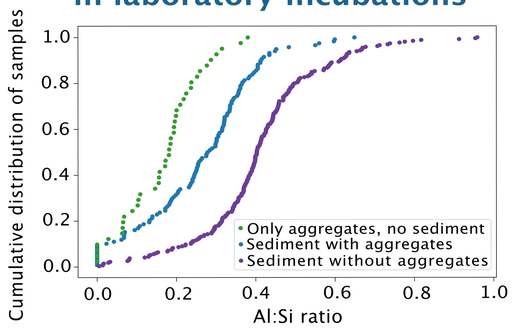
Extracted





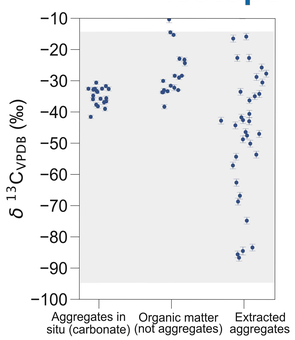
The left panel shows purported ANME-SRB aggregates that were inside seep carbonates collected off the coast of Costa Rica. a. and b. are scanning electron microscopy (SEM) images and c. and d. are fluorescence images after staining with DAPI (binds to DNA). The right panel shows an extracted ANME-SRB aggregate under SEM (e) and light microscopy (f), and fluorescence images of DAPI staining for DNA (g) and specific for ANME (RED) and SRB (green) (h). Some of these are included in [2].

They also enhance Si precipitation in laboratory incubations



The aluminium:silica ratio was lower for 49 sediment-free lab. incubations of aggregates than for 385 samples of aggregate-attached and aggregate free sediment collected at 3 different methane seeps on the Pacific Ocean of California and Costa Rica [2].

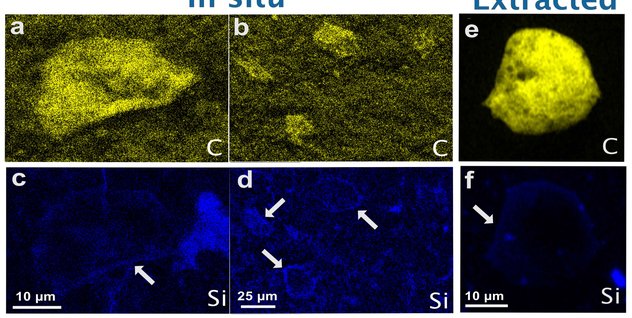
They have a distinctive C isotope signature



- Aggregates extracted from modern carbonates have a wide range of $\delta^{13}C$ values, similar to that of aggregates in sediment (shaded region; from [3] and [4]).
- Aggregates and organic matter in carbonates have much narrower and on average heavier $\delta^{13}C$ values.
- We don't have yet an explanation for this, but it could be relevant for the use of $\delta^{13}C$ as a proxy for fossil ANME-SRB aggregates.

where they enhance Si precipitation

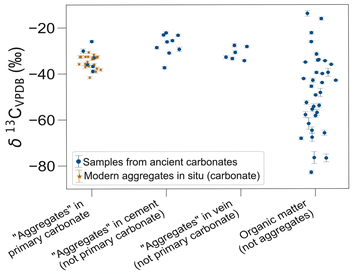
In situ



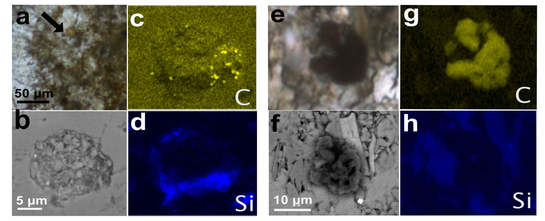
Extracted

These are X-ray diffraction compositional maps of the aggregates with the same letter shown in the above figure, for carbon (a, b and e), and silicon (c,d and f). Aggregates tend to be in close proximity to Si or forming Si rims (arrows). Some of these are included in [2].

How do we find ANME-SRB aggregate fossils?



Just like modern ANME-SRB aggregates, features that look like aggregates in ancient carbonates have a much narrower range of $\delta^{13}C$ values than extracted aggregates or aggregates from sediment.



Examples of purported aggregates in seep carbonates from the Moreno Formation of Northern California (~ 65 Mya). a. and e. are light microscope pictures; b. and f. are SEM pictures of the purported aggregates show in a. and e., respectively; c. and. g are maps of carbon and d. and h. are maps of silicon.

Key findings:

The proxies to find fossils of aggregates formed by the anaerobic methanotrophic archaea (ANME) and sulfate-reducing bacteria (SRB) symbionts in ancient carbonates identified so far are:

- Si-Al forming a ring around the aggregate/homogeneous inside the aggregate (colocalizing with C).
- 5 to ~50 µm, distinctive shape and appearance in reflected light.
- $\delta^{13}C$ signatures comparable to those of modern aggregates in carbonates in situ (-30 to -45 ‰).
- Embedded in primary carbonate textures.

However, none of these characteristics is exclusive of ANME-SRB aggregates.

Acknowledgements

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References

[1] Chen, Y., Li, Y. L., Zhou, G. T., Li, H., Lin, Y. T., Xiao, X., and Wang, F. P. (2014). Biomineralization mediated by anaerobic methane-consuming cell consortia. Scientific reports, 4, 5696 **[2]** Metcalfe, K.S., Osorio-Rodriguez, D., Yu, H., Dekas, A.E., Grotzinger, J.P. and Orphan, V.J. Silicate biomineralization of sediment- and carbonate-hosted archaeal-bacterial consortia during the anaerobic oxidation of methane and implications for microbial fossil preservation (in prep.). **[3]** Orphan, V. J., House, C. H., Hinrichs, K. U., McKeegan, K. D., and DeLong, E. F. (2001). Methane-consuming archaea revealed by directly coupled isotopic and phylogenetic analysis. Science, 293(5529), 484-487. **[4]** Orphan, V. J., House, C. H., Hinrichs, K. U., McKeegan, K. D., & DeLong, E. F. (2002). Multiple archaeal groups mediate methane oxidation in anoxic cold seep sediments. Proceedings of the National Academy of Sciences, 99(11), 7663-7668.