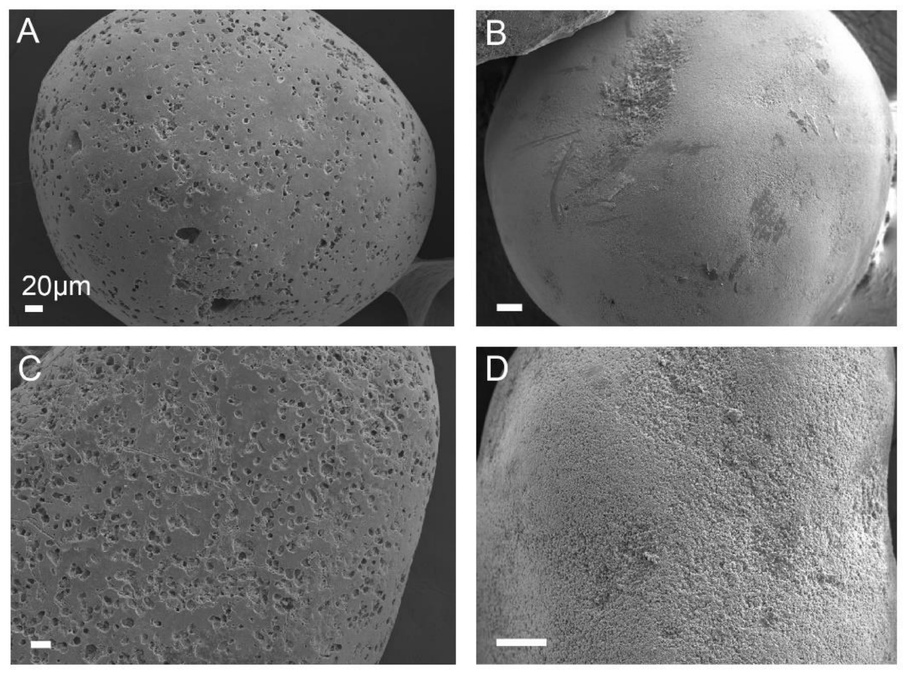
Ecophysiology of ooid microborings excavated by endolithic Cyanobacteria

Usha F. Lingappa[1], Woodward W. Fischer[1], Elizabeth J. Trower[2]

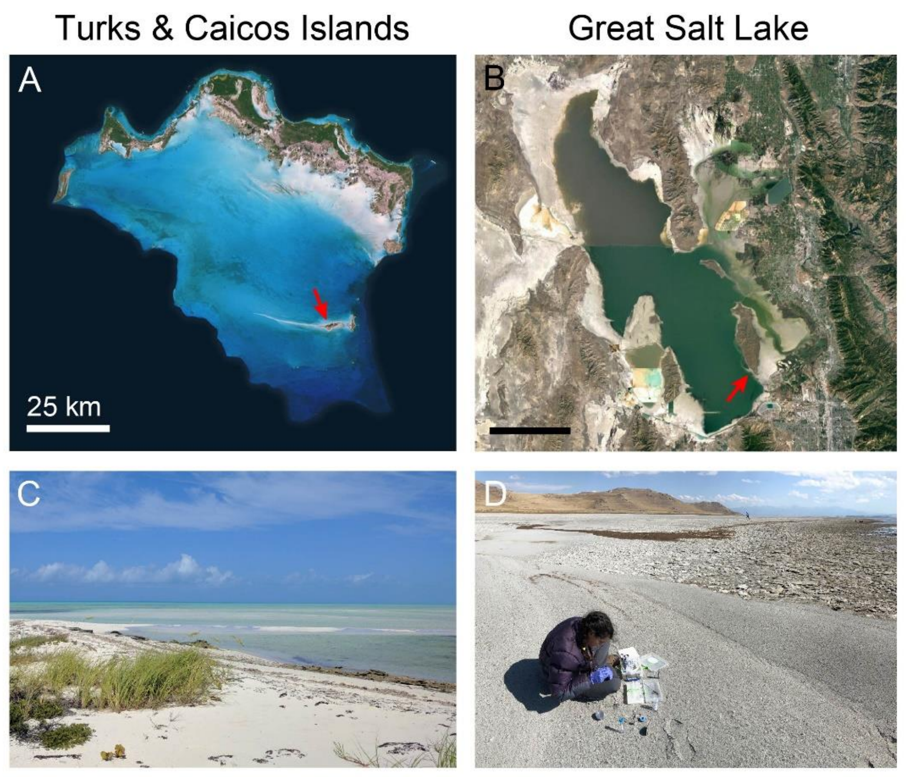
1. Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena CA
2. Department of Geological Sciences, University of Colorado Boulder, Boulder CO

Introduction



Boring Cyanobacteria are ubiquitous in $CaCO_3$ sediments on modern carbonate platforms, but rare or absent from within many modern lacustrine carbonate sediments and some ancient marine carbonate strata.

Fig. 1: Ooids with (A,C) and without (B,D) microborings from the Turks and Caicos Islands and the Great Salt Lake, respectively.



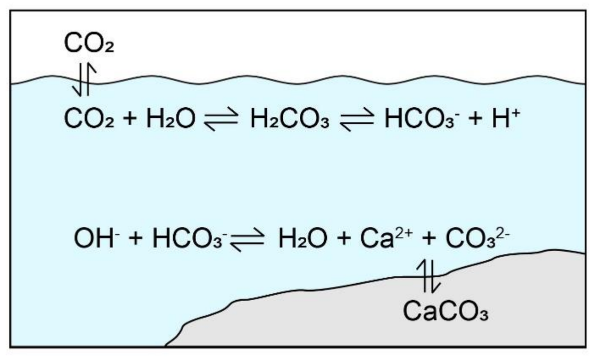
Hypothesis: the difference in water chemistry between TCI and GSL determines the feasability of the boring lifestyle.

Implication: the presence or absence of borings in the geological record can be used as a paleoenvironment proxy.

Fig. 2: Satellite images (A,B) and context photos (C,D) of field sites in this study. Marine field site is on Little Ambergris Cay in the Turks and Caicos Islands (A,C), and lacustrine field site is on Meira Spit near the southwestern end of Antelope Island in the Great Salt Lake, UT (B,D).

Process and mechanism

$$CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca^{2+} + 2HCO_3^-$$



Carbonate dissolution is a form of carbon compensation, and an important buffering system against ocean acidification from rising pCO_2.

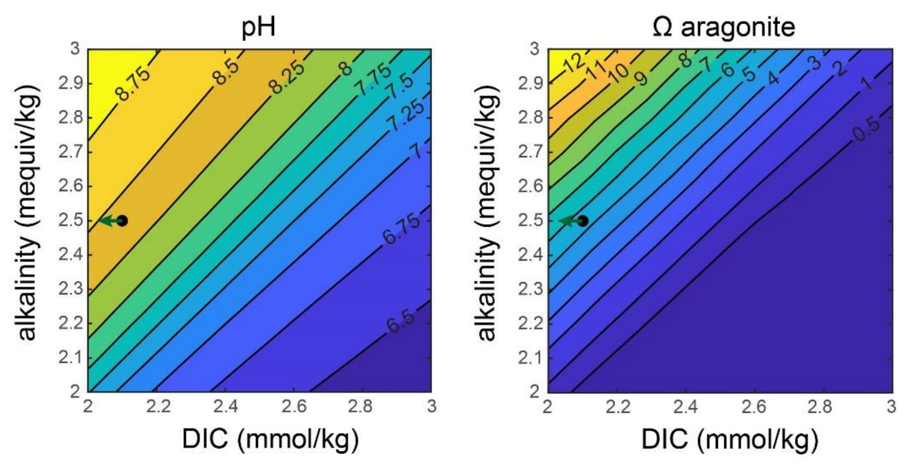
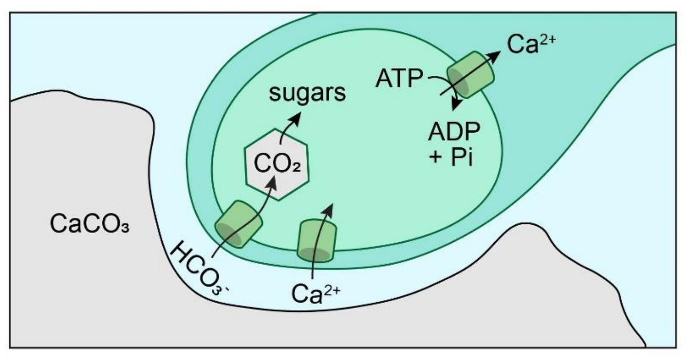


Fig. 3: Fan diagrams illustrating contours of pH and Ω aragonite, in alkalinity vs. DIC space. Black dots show approximate composition of Caicos platform seawater, at pH ~8.3 and Ω ~5. Green arrows indicate the effect of Cyanobacterial photosynthesis.

Photosynthesis should increase carbonate precipitation rather than dissolution.

Active Ca^{2+} pumping mechanism allows carbonate dissolution independant of pH in boring model system *Mastigocoleus testarum* strain BC008.



Mechanism described in Garcia-Pichel, et al., 2010, *PNAS*.

Boring occurs on surprisingly fast timescales

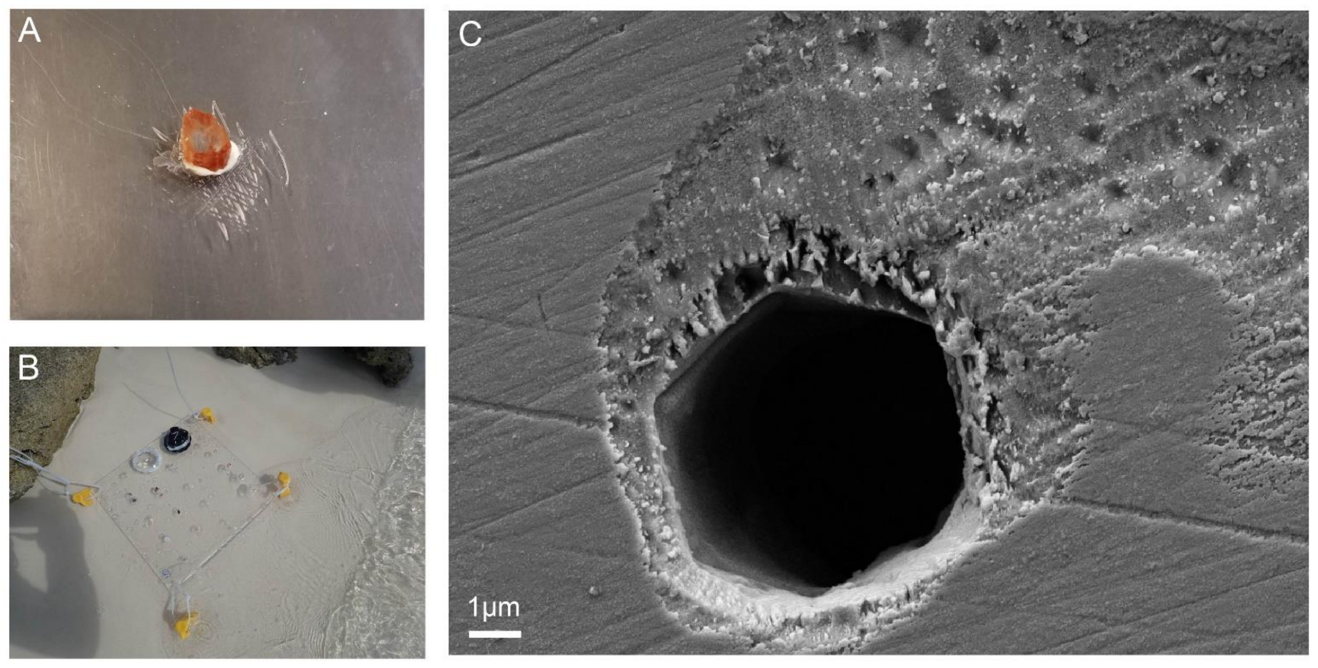


Fig. 4: An experimentally tractable system to study boring in the environment. A) Witness plates of abiogenic, sterile aragonite from the Caltech mineral collection were polished and glued to plexiglass sheets, and B) deployed in situ in the Turks and Caicos field site for incubation periods of 5-10 days. C) Boring was observed using secondary electron microscopy.

Physical environment controls boring frequency

Fig. 5: Experimental locations on Little Ambergris Cay, TCI. Little Ambergris Cay is a tiny uninhabited island comprised of a carbonate grainstone bedrock rim, surrounding an interior lagoon. An ooid shoal stretches for ~20km to the west. A) Satellite image indicating shoal, beach, and lagoon. B-C) context photos of beach (B) and lagoon (C) locations of aragonite stub experiments.

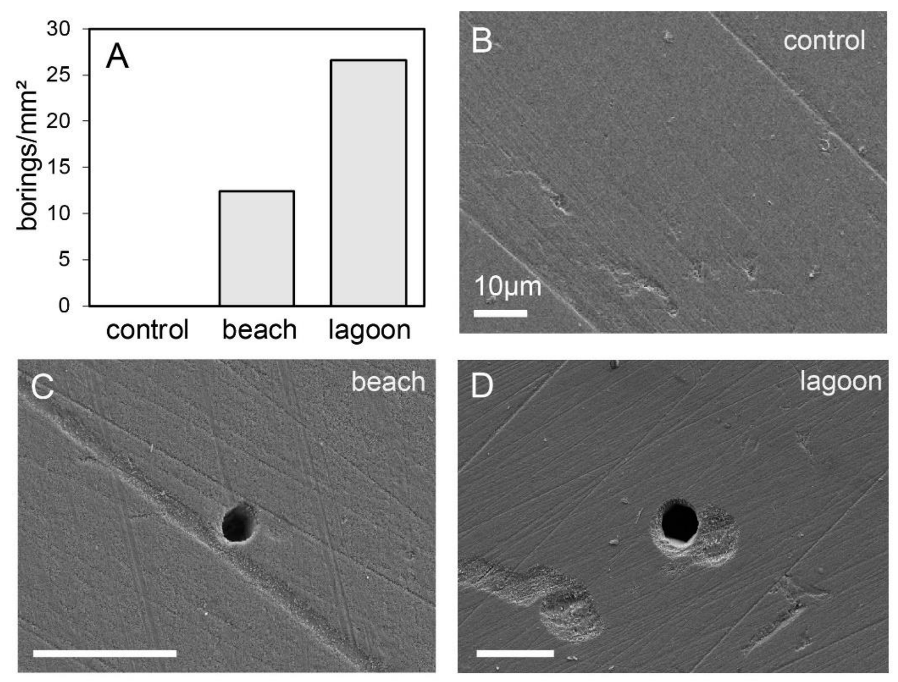


Fig. 6: Differential boring frequency in beach vs. lagoon settings. A) Borings per area counted on aragonite stubs from different locations. B-D) example SEM images from control (B), beach (C), and lagoon (D) settings. We observe ~2x more borings in interior lagoon relative to exterior beach

Borings are colonized by complex microbial communities

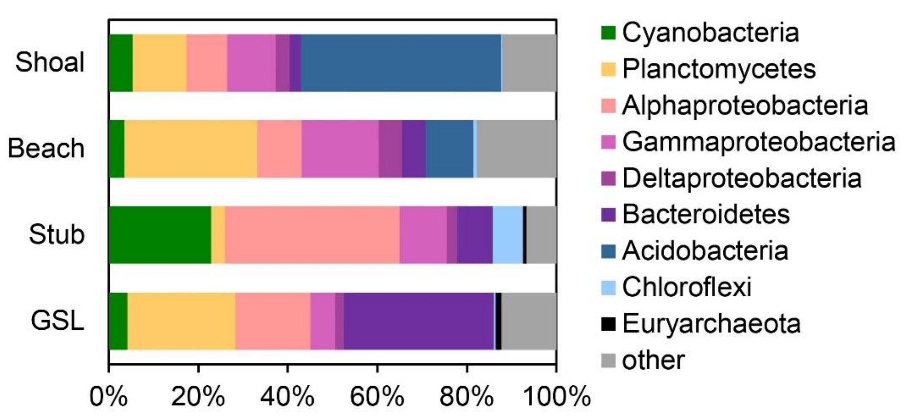
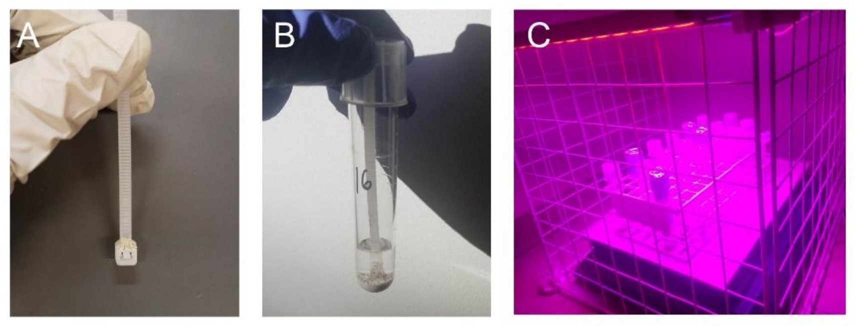


Fig. 7: Phylum-level microbial diversity by 16S rRNA gene amplicon sequencing on DNA extracted from powdered ooids from the LAC shoal and beach, aragonite stubs deployed in the LAC lagoon, and powdered ooids from the GSL.

Boring is more versatile than previously appreciated



D

Medium	Inhibitor	Bored?
ASW	None	Yes
ASW	TBHQ	Yes
ASW	Dark	Yes
GSL water	None	Yes
GSL water	TBHQ	Yes
GSL water	Dark	Yes

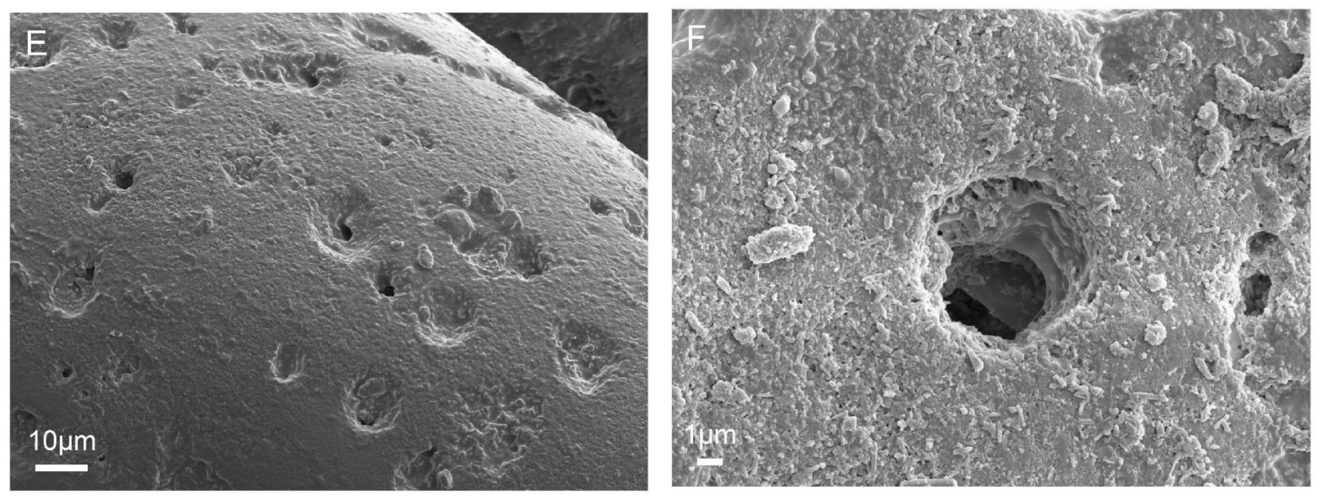
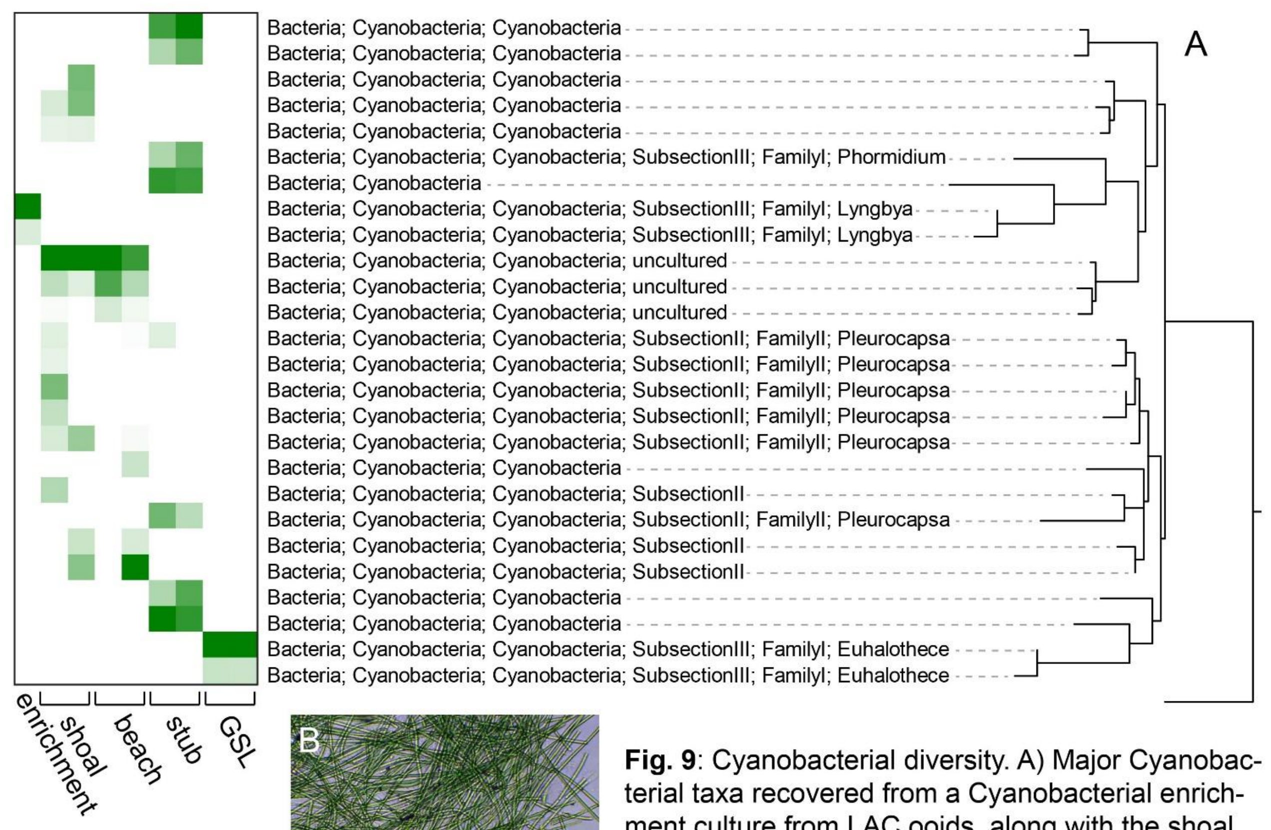


Fig. 8: Incubation experiments to probe boring mechanism. A-C) Experimental setup. A) Unbored GSL ooids were glued to zipties. B) Immobilized GSL ooids were incubated in culture tubes innoculated with live LAC ooids, in different water chemistries, and with and without light and Ca-ATPase inhibitors. C) For experiments conducted during fieldwork, tubes were incubated on a shaker table under blue and red LEDs. Subsequent experiments in the lab at Caltech were incubated in a 30°C shaking incubator under white fluorescent lights. D) Table of incubation conditions and results. Boring was observed in all conditions. E-F) Example SEM images of borings in immobilized GSL oodis from incubations.

Diverse Cyanobacteria in LAC boring systems are distinct from GSL Cyanobacteria



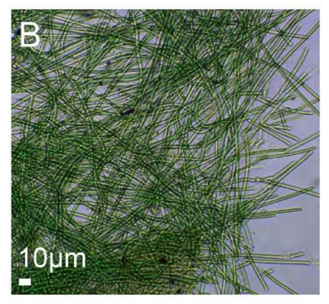


Fig. 9: Cyanobacterial diversity. A) Major Cyanobacterial taxa recovered from a Cyanobacterial enrichment culture from LAC ooids, along with the shoal ooids, beach ooids, aragonite stubs, and GSL ooids samples from Fig. 7. B) Light microscopy of filamentous Cyanobacterium enriched from LAC ooids.

Conclusions

Remarkably rapid rate suggests boring represents a process controlling meaningful fluxes of carbon cycling in shallow marine waters.

Better understanding the diversity of Cyanobacteria implicated in boring and the physiologies and mechanisms of carbonate dissolution that they employ may provide important insight into carbon compensation in sunlit environments.

The ability of LAC Cyanobacteria to bore GSL ooids in GSL water suggests that the difference between LAC and GSL is ecological rather than purely geochemical.

Understanding what conditions select for boring will help us better understand the boring geological record.

Caltech
University of Colorado Boulder
AGOURON INSTITUTE
NSF
NASA