PS Pre-Salt Spherulites: Bacterially Induced Initiation of Precipitation*

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Abstract

Carbonate spherulites form widespread accumulations in the Aptian Pre-Salt deposits in the Campos Basin, offshore Brazil. The calcite spherulites commonly range from 1 to 2 mm in diameter. Petrographic sections through their cores display either a fine-grained nucleus or pore space, and are surrounded by well-developed radiating carbonate crystal cortices. Primary porosity is common between the spherulites, whereas some pore spaces are occluded with authigenic precipitates (e.g., dolomite, chert, and megaquartz), other reported sites have a stevensite matric. The spherulites investigated commonly display interpenetration compaction against other spherulites with no inter-spherulitic material. Spherulites from the Pre-Salt are very similar to spherulites from modern hot springs (Yellowstone National Park), cold geyser (Crystal Geyser, Utah), tufa (Searles Lake, California), rock record travertine (Belen, New Mexico), and caliche (West Texas) deposits.

Petrographic and SEM analyses of these non-Pre-Salt spherulites show that they are composed of a fine-grained nucleus of carbonate encrusted bacterial bodies and a cortex of radiating crystals of aragonite or calcite. The bacterial colonies in the nucleus induced the precipitation of carbonate, overcoming the inhibition to initiate crystal formation. The radiating crystals comprising aragonitic cortices grew abiotically producing well-formed euhedral crystals with a paucity of included bacterial fossils. Those cortical crystals made-up of calcite commonly contained an abundance of bacterial fossils, indicating that the bacterial colonies contributed to the precipitation of the cortical calcite crystals. The aragonitic crystals probably precipitated rapidly in highly supersaturated conditions (e.g., modern hot springs at Yellowstone), whereas the calcitic cortices precipitated in moderately saturated conditions (e.g., Texas caliche) and thus bacterial growth kept up with cortical growth. The Pre-Salt spherulites most likely also initiated carbonate precipitation around bacterial colonies while the spherulites were afloat in a lacustrine water column. The spherulite-to-spherulite compaction with an absence of inter-spherulite sediment indicates that cortical crystal growth continued while the spherulites were either still afloat or at the sediment-water interface rather than displacively within the sediment and that compaction occurred with burial.

Analogues for the Pre-Salt Spherulites: Bacterially Induced Initiation of Precipitation

Henry Chafetz, Earth & Atmospheric Sciences, University of Houston

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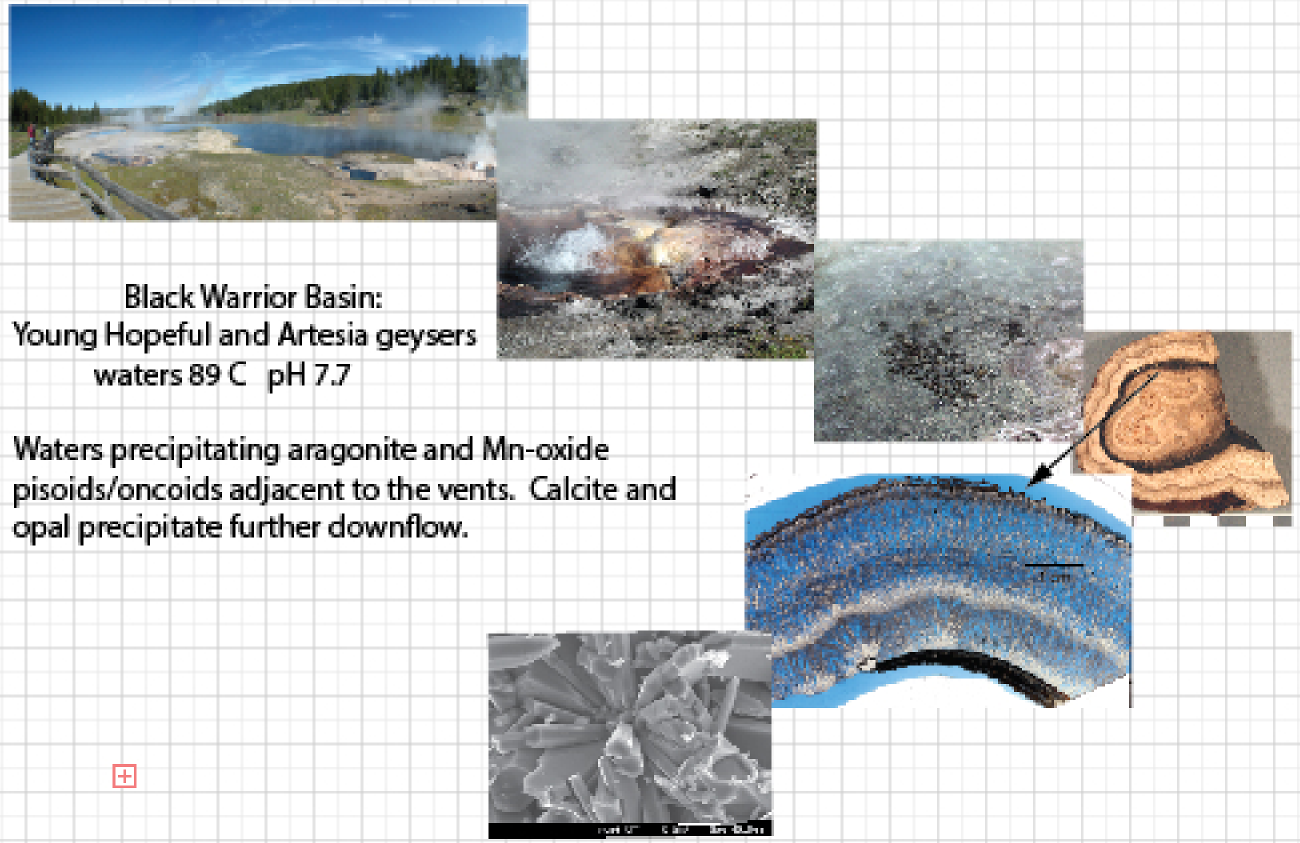
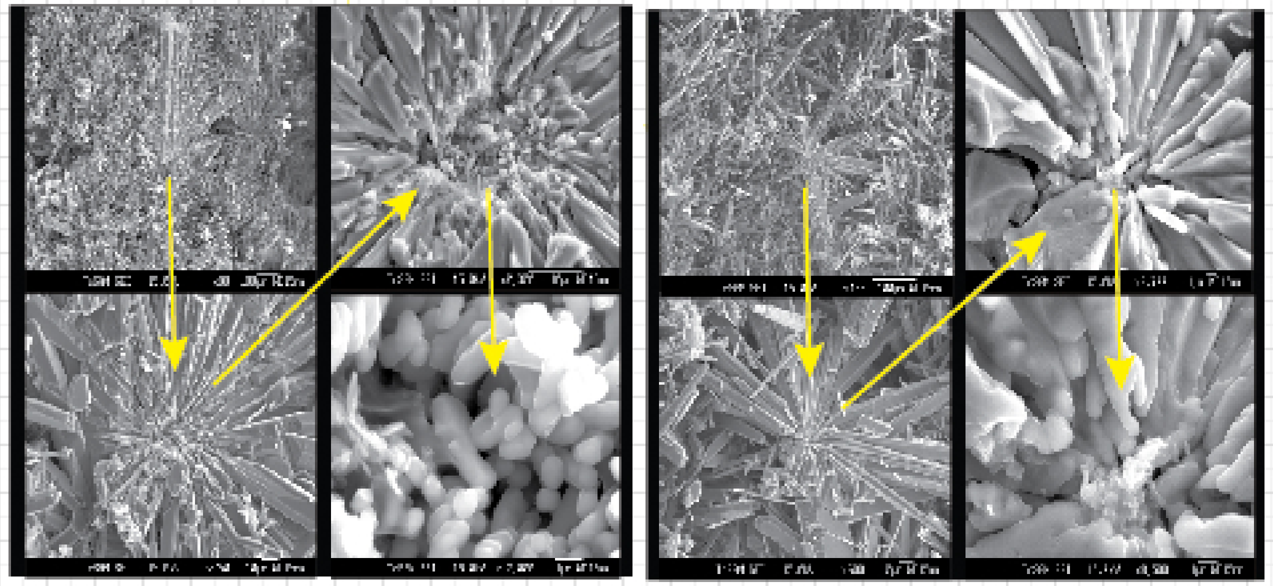
Yellowstone National Park, Wyoming



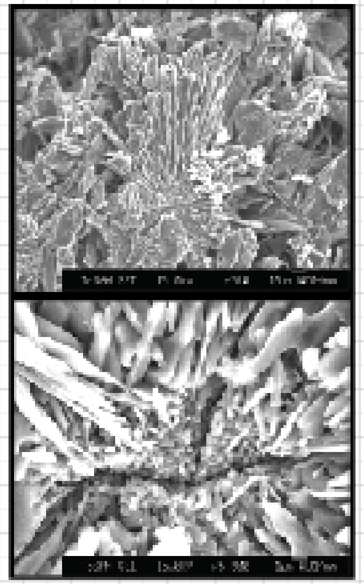
Black Warrior Basin:
Young Hopeful and Artesia geysers
waters 89 C pH 7.7

Waters precipitating aragonite and Mn-oxide pisoids/oncoids adjacent to the vents. Calcite and opal precipitate further downflow.

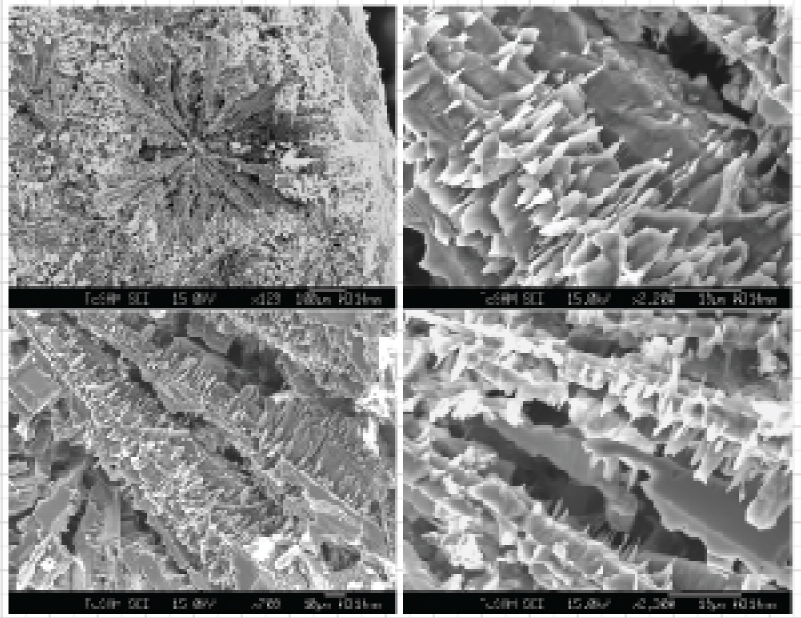
Two aragonitic spherulites with their nuclei composed of bacterial bodies, crystals comprising cortex in left set of photos are devoid of bacterial fossils whereas in second set of photos bacterial bodies are incorporated within portions of aragonite crystals immediately adjacent to nuclei.



HCl etched spherulite, no fossils evident within cortical crystals.

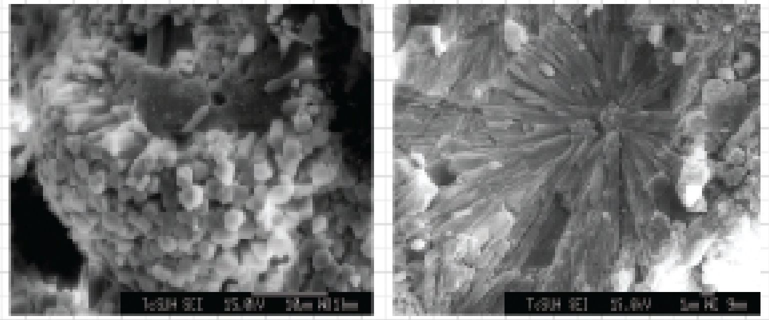


Abiotic spherulites, Yellowstone hot spring, no bacterial fossils evident. Observe bizarre habit of aragonite crystals comprising the cortices. Precipitation is presumed to have occurred under very high supersaturation.

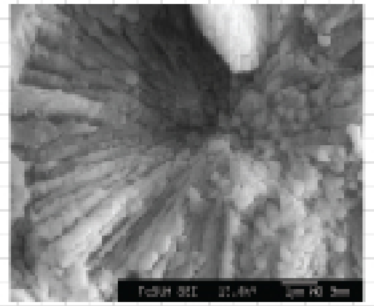


Crystal Geyser, Utah

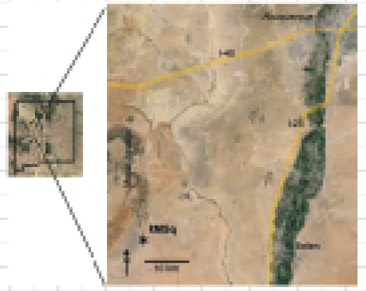
Aragonitic spherulites have bacterial fossils as their nulei, none or sparse fossils in their cortices.



Calcitic spherulite with bacterial fossils comprising nuleus as well as cortical crystals.



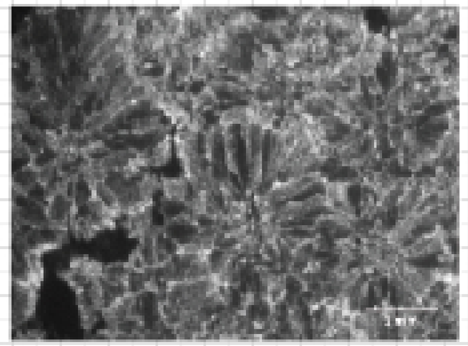
Rocky Mountain Stone quarry, Belen, New Mexico

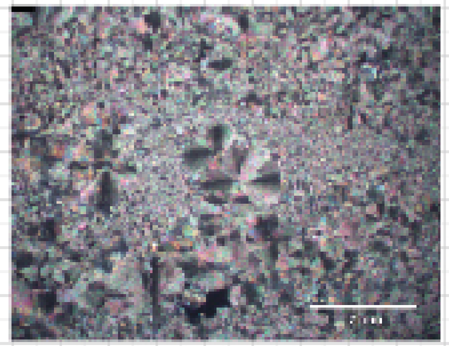


RMSq: quarry site
(Google Earth photo)

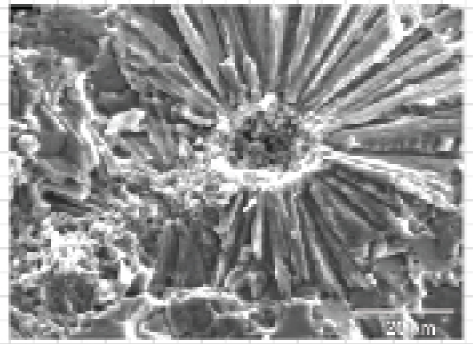
Sloping travertine fan accumulation, western margin of Rio Grande Rift Basin. (EB = extraformational breccia).

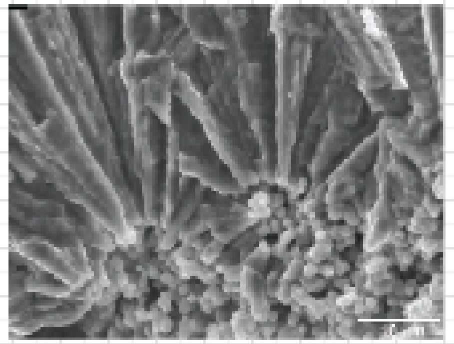
Photomicrographs of spherulites from RMSq.



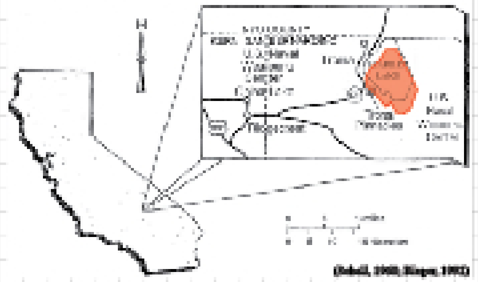


SEM views of calcitic spherulites from RMSq, observe bacterial fossils comprising nuleus as well as in the cortical calcite crystals.



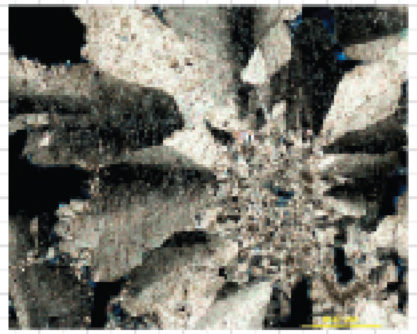


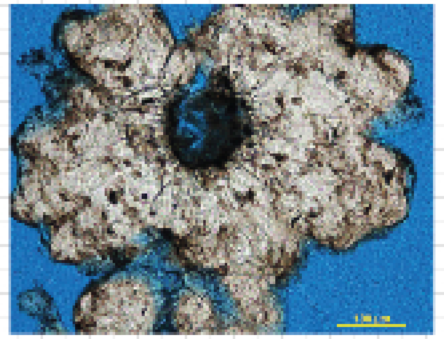
Searles Lake, California



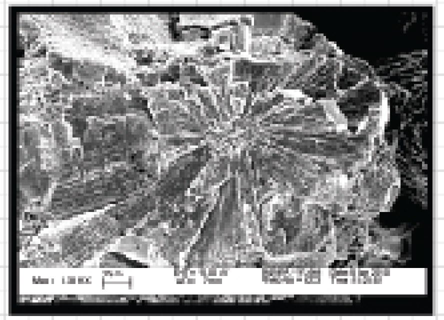
Tufa mounds

Photomicrographs of spherulites from Searles Lake tufa mounds. Observe the fine-grained nucleus within radially arranged calcite cortex on the left and on the right observe hole due to selective dissolution of the center of the radially arranged calcite crystals.

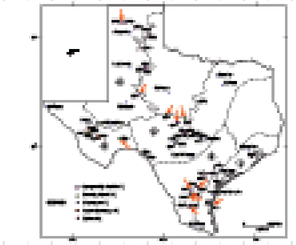




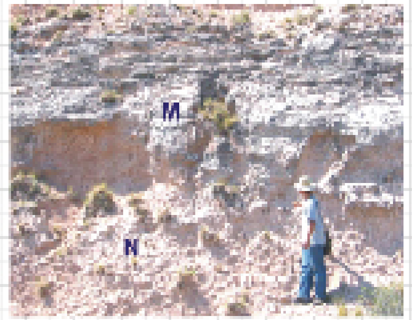
SEMs of spherulite with fine-grained nucleus, high resolution of cortices shows that the cortical calcite crystals contain bacterial fossils.



Texas caliches

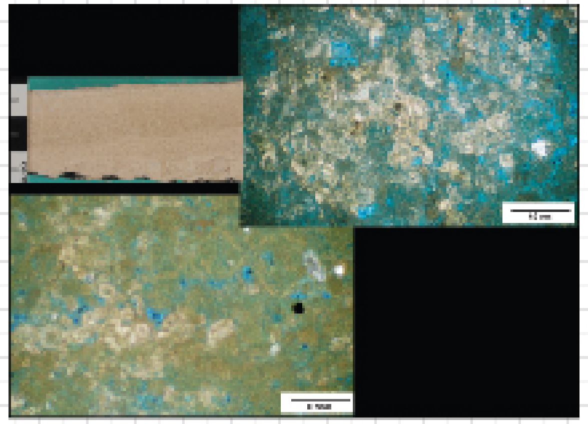


Map of Texas with sampling locations indicated.

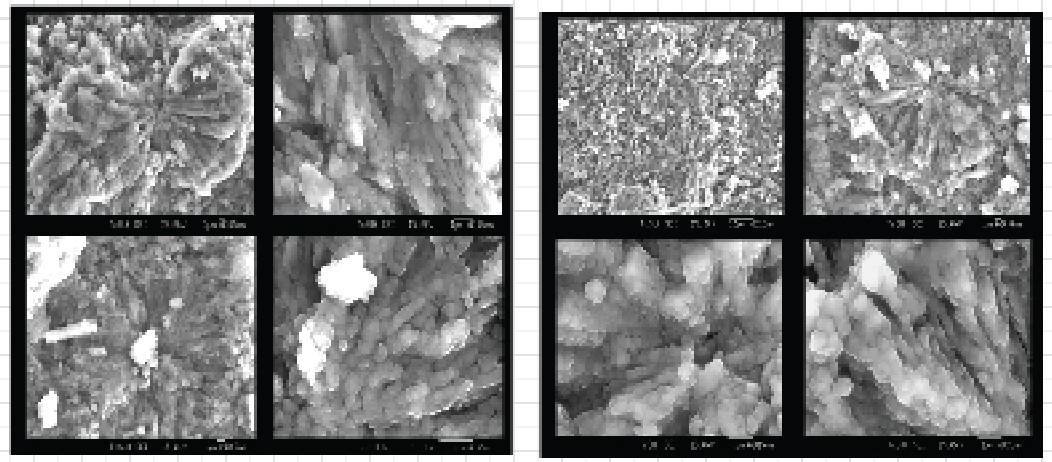


Field photograph of a Texas caliche outcrop's nodular (N) and massive (M) horizons.

Slab view and two photomicrographs of spherulite deposits within caliches.



SEMs of spherulites showing that these calcitic allochems contain an abundance of bacterial fossils throughout their nuclei and cortices.



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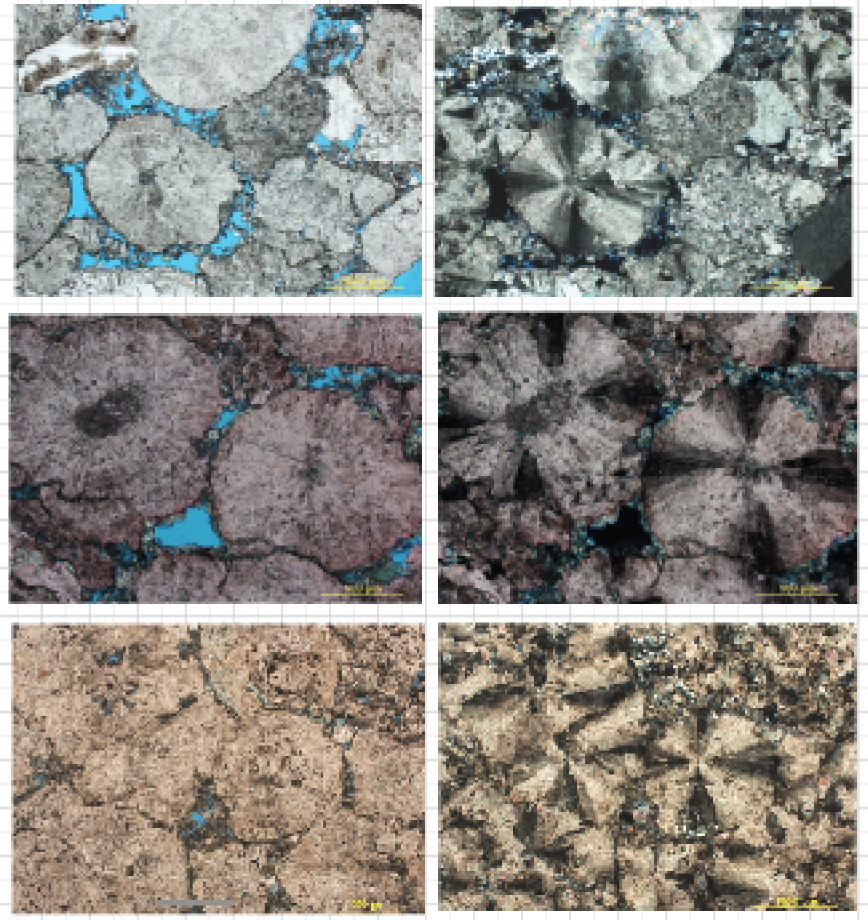
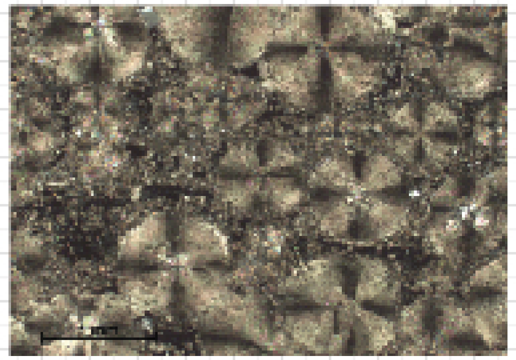
Pre-Salt Spherulites

Plane and crossed-polar photomicrographic pairs of spherulites from the Campos Basin display fine-grained nuclei, well-developed radiating cortices, and an abundance of interspherulite porosity. Adjacent spherulites commonly show compaction against on another with no indication of previous inter-allochemical sediment.

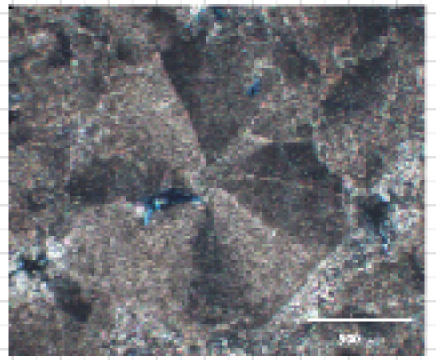


Pre-Salt



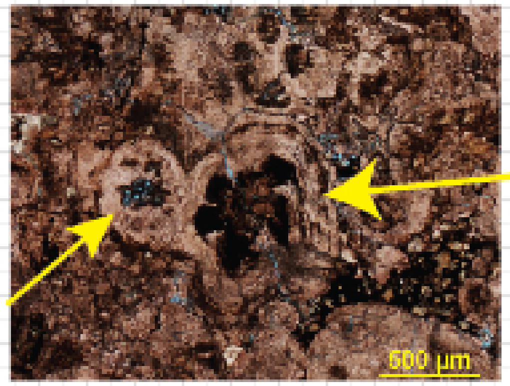
Santos Basin (modified from Terra et al., 2009)

Non-Pre-Salt

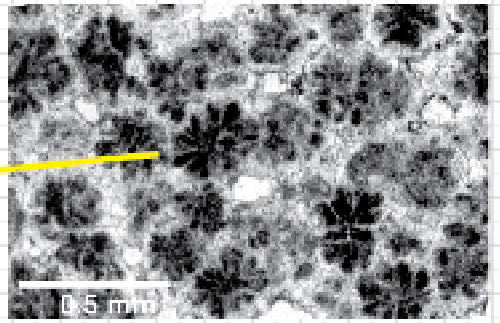


Belen travertine

dissolved nucleus



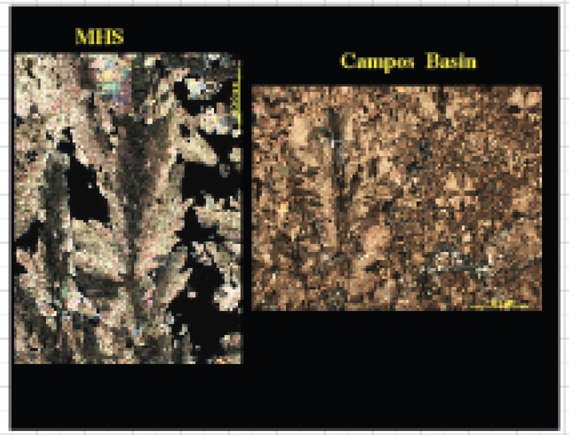
Campos Basin

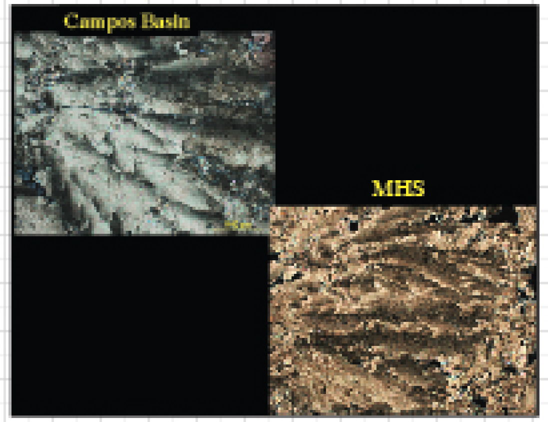


Mammoth Hot Spring, Yellowstone

Nucleus of many of the spherulites display micritic cores or holes, i.e., selectively dissolved micritic(?) cores, whereas some are very similar to bacterial peloids that occur in abundance in travertines.

Examples of other similarities between the Pre-Salt and other travertines (MHS = Mammoth Hot Spring, Yellowstone).





Interpreted Origin of the Pre-Salt Spherulites

Bacteria have been demonstrated in numerous studies to readily induce precipitation of carbonate (Kellermann and Smith 1914; Gerundo and Schwartz 1949; Lalou 1957; Krumbein and Cohen 1977; 1979; Buczynski and Chafetz 1991).

As shown by Morita (1980), bacterial bodies have a negative charge which readily attracts Ca ions in the water. These Ca ions bind to carbonate in the water, over-coming the inhibition of initial crystal lattice formation. Once this inhbition is over come, it is easy for continued crystal growth in reactant-rich waters.

Spherulites from travertines, tufas, caliches, have similar nuclei and petrographic, CL, SEM studies show them to have bacterial body fossils within nuclei.

Bacteria make very poor fossils, within 96 hours after enveloped in calcite or aragonite they have been observed to decay leaving no detectable cell structure (Krumbein et al., 1977, Krumbein 1979). This propensity to decay can explain the commonly observed dissolution holes in the center of the spherulites.

Nuclei of Pre-Salt spherulite are commonly micritic or voids (see Terra et al., 2009, fig. 21; Saller 2016, fig 12; this report figures to the left), i.e., nuclei differ from cortical crystals.

This study interprets these Pre-Salt spherulites to have initiated formation around clumps of bacteria floating in lacustrine waters. Initial growth of the cortices may have taken place in the water column whereas continued precipitation probably occurred at the sediment-water interface.

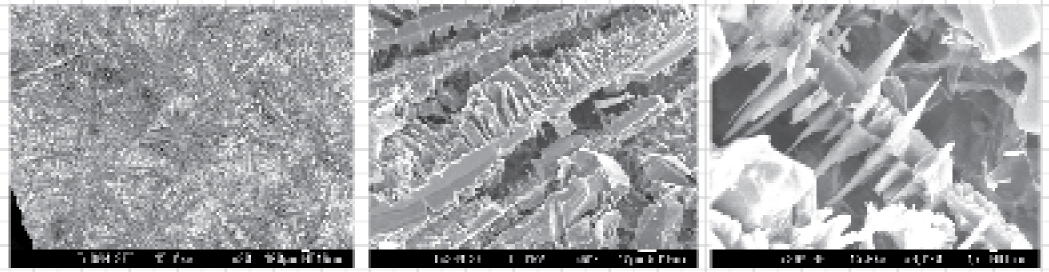
Caveat: although I have analysed Pre-Salt cores and many thin sections for companies, unfortunately, after numerous requests, I have never been able to obtain Pre-Salt spherulites for SEM or geochemical analyses; if you have any, I would greatly appreciate that opportunity.

Abiotic vs Biotic Spherulites

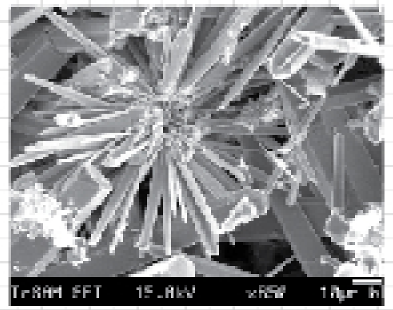
abiotic vs biotic nuclei vs bacterially induced nuclei & cortices

Precipitation of some spherulites appear to be strictly abiotic, under what are presumed to be highly supersaturated conditons, shown in the top 3 SEMs below (samples from a Yellowstone hot spring). At lower supersaturation conditions bacterial colonies act to over come the initial inhibition of crystals to form, and thus form the nuclei around which the abiotic aragonitic radial cortical structure forms. At low saturation conditions, such as in caliche deposits, bacterial growth continues during precipitation of the cortical crystals, and thus, are incorporated throughout the calcitic spherulitic allochems.

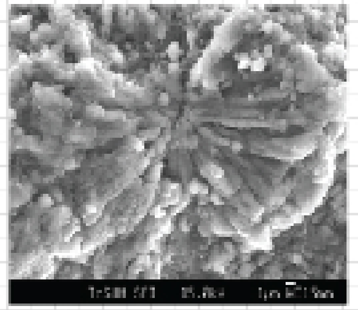
Strictly abiotic: no bacterial influence: aragonite



Bacterial nucleus: bacteria initiate mineral precipitation: abiotic cortices: aragonite



Bacterially induced precipitation of nucleus & cortices: calcite



Errors in the interpretation are those of H. Chafetz. Figures from different studies:
Yellowstone: H. Chafetz;
Crystal Geyser: Barth and Chafetz (2015, Sedimentology 62, 607-620);
Rocky Mountain Stone quarry: Cook and Chafetz (2017, Sedimentary Geology 352, 30-44);
Searles Lake: Guo and Chafetz (2012 and 2014, Sedimentology 59, 1509-1535 and 61, 221-237);
Texas caliches: Zhou and Chafetz (2009, Sedimentary Geology 222, 207-225),
(2010 Journal of Sedimentary Research 80, 136-150), and (2012 SEPM Spec. Pub. 101, 191-198);
Pre-Salt H. Chafetz (with permission to publish from a major petrochemical comany).