The role of climate change in mass extinctions: Using stromatolites to constrain temperatures during times of biotic crisis

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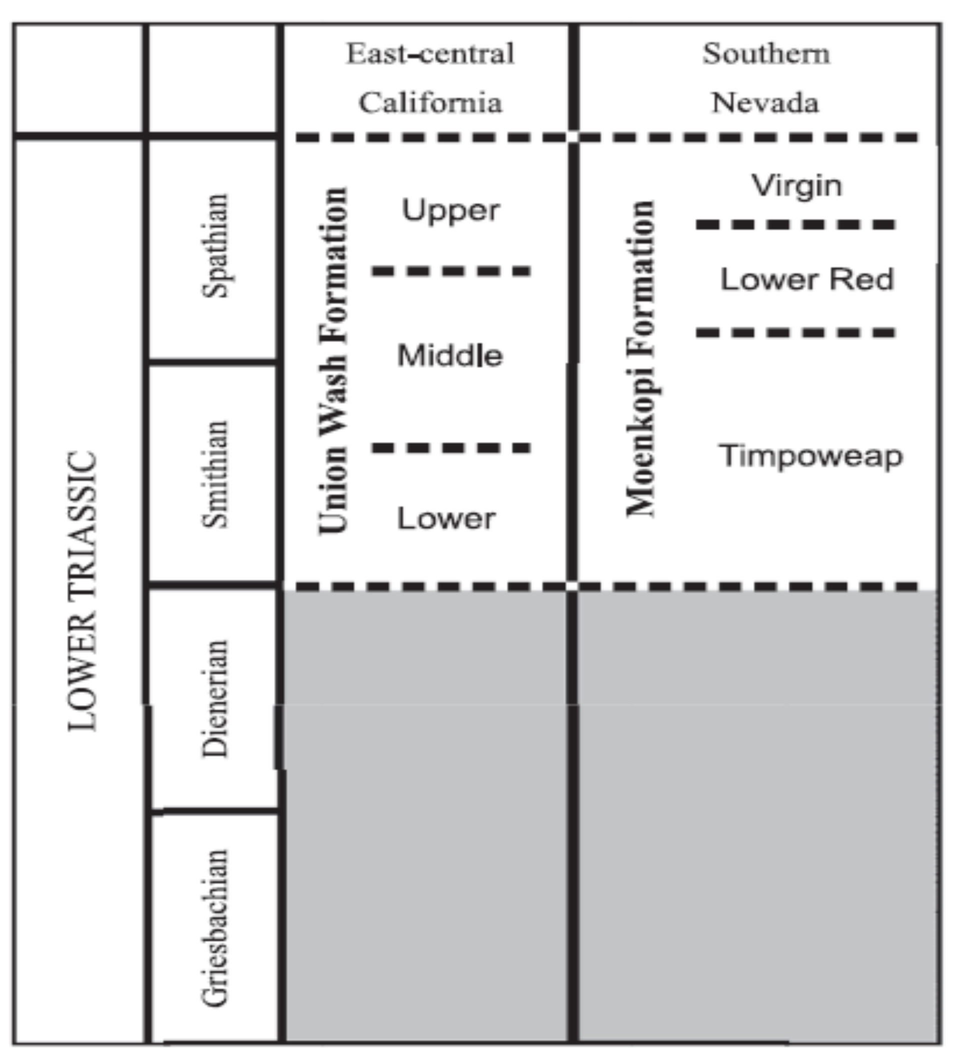
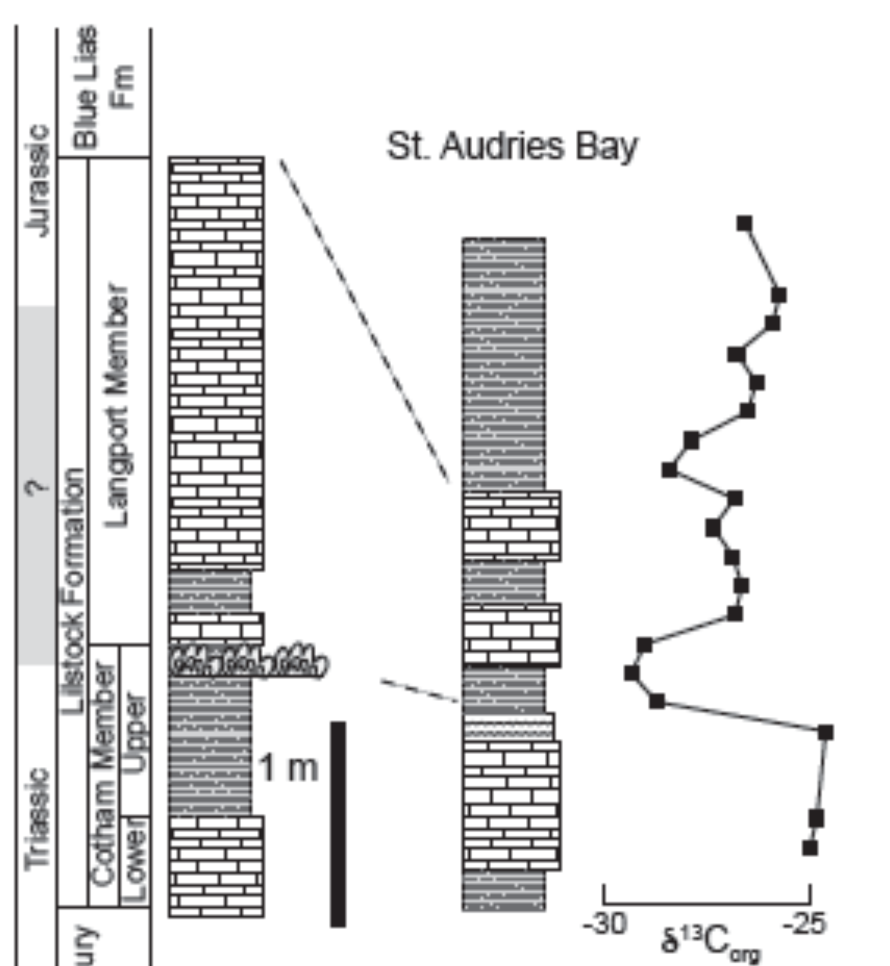
Abstract: Stromatolites are laminated sedimentary structures that are accretionary away from a point or surface These structures are commonly thought to be created by cyanobacteria, either through the trapping and binding of sediment, or through metabolically-induced precipitation. Stromatolites first appear early in the fossil record (~3.8 Ga), and increase in form diversity through the Proterozoic. The occurrence of stromatolites in the fossil record decreases before the Precambrian-Cambrian boundary, and strikingly they subsequently only re-emerge in abundance at times of biotic crisis, such as the Permian-Triassic and Triassic-Jurassic extinctions. Both of these mass extinctions are coincident with large scale volcanism. Associated increases in atmospheric CO_2 caused increases in ocean acidity and increases in global temperatures, and these environmental perturbations are hypothesized to have been key drivers of mass extinction, along with anoxia and euxinia. In order to understand the role of climate change in mass extinctions, we are estimating temperatures across both boundaries using stromatolites. Specifically, we are applying the carbonate "clumped" isotope paleothermometer to well-preserved specimens that have been petrographically examined in order to ascertain their temperature of formation during extinction and recovery intervals. Samples were collected from the Lower Triassic Virgin Limestone (Lost Cabin Springs, SW Nevada) and the Cotham Member(Triassic-Jurassic boundary interval, Bristol, United Kingdom). Subsequent to petrographic analysis, samples were micro-drilled to obtain primary phases. The resultant carbonate powder was then analyzed for clumped isotopes using a mass spectrometer at UCLA. Here we present preliminary data to assess sample alteration

Background: The Permian-Triassic Mass Extinction coincident with volcanic eruptions in Siberia. Volcanically-induced increases in CO_2 would have led to increases in temperature and decreases in oxygen solubility in shallow water environments.

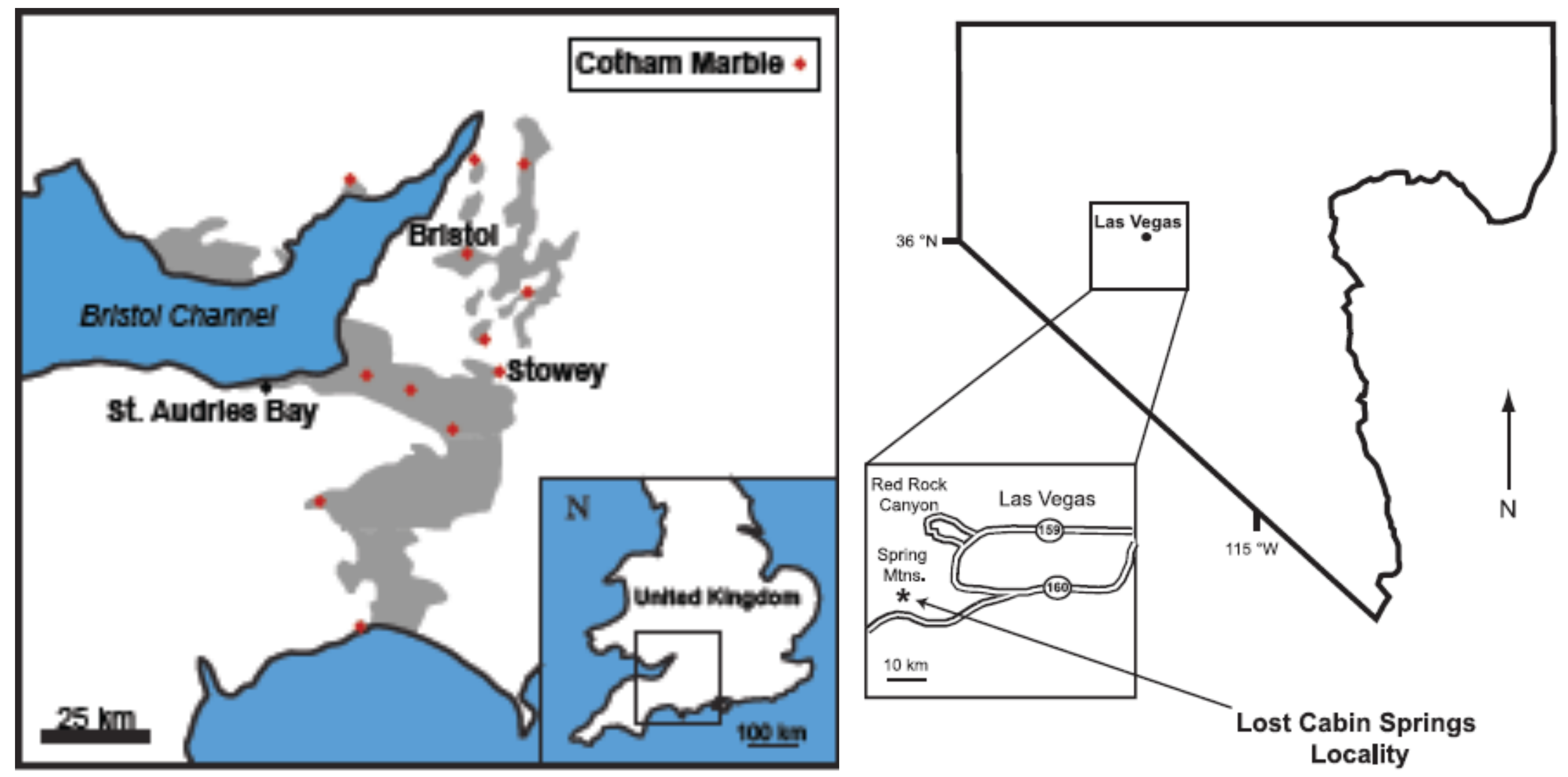
The Triassic-Jurassic Mass Extinction is also thought to be associated with volcanic activity, with volcanism associated with the Central Atlantic Magmatic Providence. The new crust formed from this volcanic activity caused the rifting of crust, and initiated the breakup of Pangaea. For this study, we examined Permian-Triassic stromatolites that were previously studied by Matta and Bottjer (2011), and Triassic-Jurassic stromatolites obtained from the UK from the Cotham Member.



Stratigraphic column showing the Permian-Triassic stromatolite samples. The samples were obtained from the Virgin Limestone member of the Moenkopi Formation (Spathian era- uppermost lower Triassic). This stratigraphic column is from Pruss and Bottjer (2004).

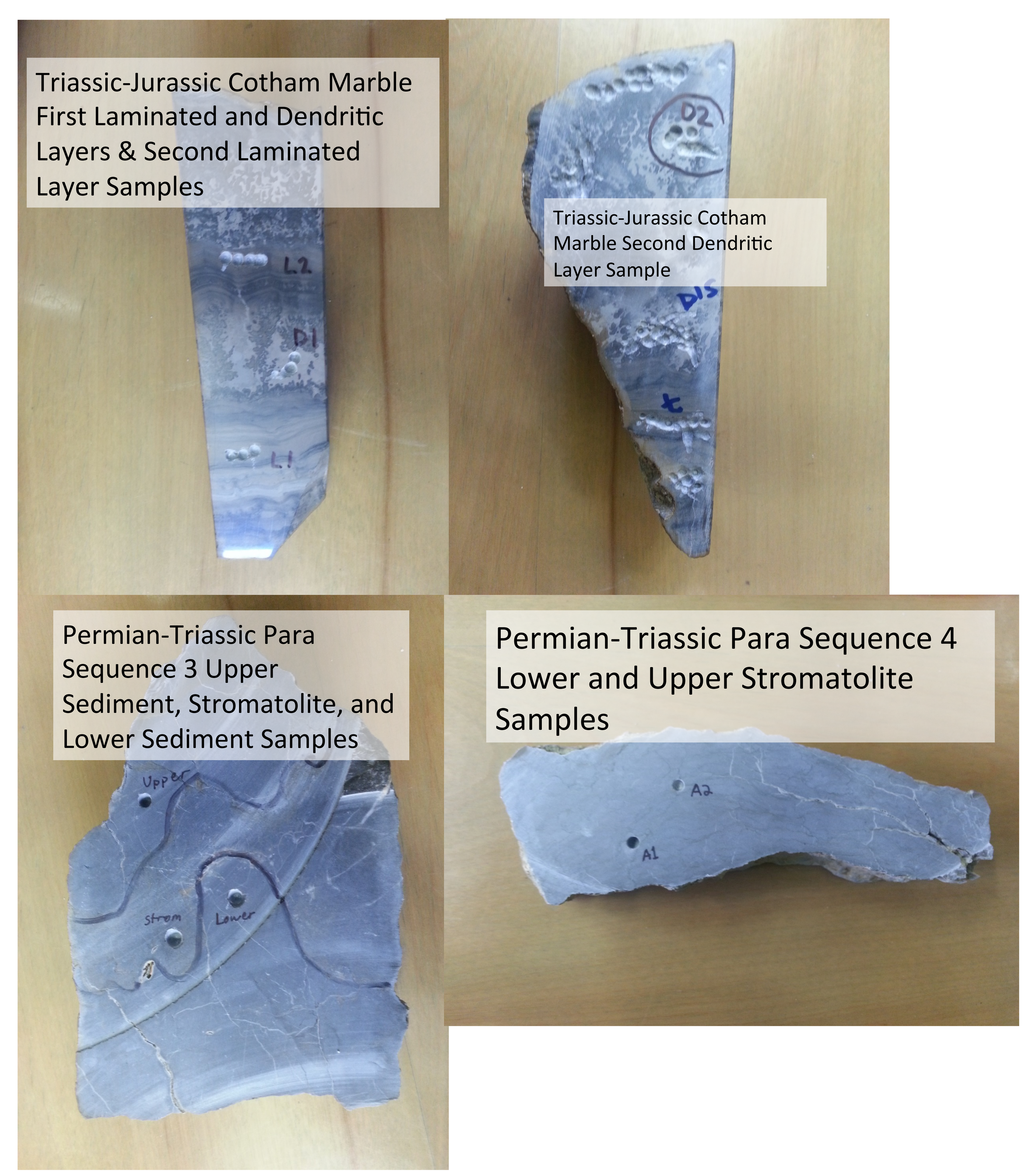


Stratigraphic column the Triassic-Jurassic stromatolite samples for section in Stowey. Samples were collected from Bristol and correlated to the section is from Stowey (also shown on the map above). This stratigraphic column is from Ibarra et al. (2013).



Maps detailing where the stromatolite samples for this project were collected. Triassic-Jurassic stromatolites were collected from Bristol, shown above on the first map and Permian-Triassic stromatolites were collected from the Lost Cabin Springs Locality. The map detailing the Triassic-Jurassic sample locality was obtained from the Ibarra et al. (2013) paper. The map detailing the Permian-Triassic sample locality was obtained from the Pruss and Bottjer (2004) paper.

Method: The Permian-Triassic and Triassic-Jurassic extinction boundary stromatolites are being analyzed using clumped isotope thermometry. In clumped isotope thermometry, the mass spectrometer measures the abundance of different isotopic species of CO_2 produced by acid digestion of carbonate minerals. At lower temperatures, heavy-isotopes (^{13}C and ^{18}O) have a tendency to form bonds with each other, or clump. The most common isotopic species of carbon dioxide is $^{12}C^{16}O^{16}O$, whereas only a small fraction of CO_2 occurs as the heavier mass-47 species $^{13}C^{18}O^{16}O$. Measuring the abundance of such heavy isotopic species can allow for the calculation of the temperature of formation within a 1-3°C certainty (Huntington 2009). Samples are reported on an absolute reference scale, with gas standards that were produced at 25 and 1000 °C. Carbonate growth temperatures are calculated using the calibration of Ghosh et al. (2006).



Sample	Number of Analyses	δ13C (V-PDB)	δ18O (V-PDB)	Δ47 T (°C) - ARF, Ghosh calibration
Triassic-Jurassic Stromatolites				
Cotham Marble Second Dendritic Layer	2	0.420	-1.438	24.6
Cotham Marble Second Laminated Layer	2	-0.712	-2.076	35.7
Cotham Marble First Dendritic Layer	2	0.130	-0.683	32.2
Cotham Marble First Laminated Layer	3	-0.063	-1.104	37.9
Permian-Triassic Stromatolites				
Para Sequence 4 Upper Sampling	1	0.652	-7.993	94.2
Para Sequence 4 Lower Sampling	1	0.608	-7.987	101.0
Para Sequence 3 Upper Sediment Sampling	2	-0.709	-7.716	94.5
Para Sequence 3 Stromatolite Sampling	3	-0.590	-7.780	112.6
Para Sequence 3 Lower Sediment Sampling	1	-0.479	-0.670	107.6

Results: Triassic-Jurassic stromatolites yielded temperatures of between 24.6 and 44.2 °C. The average temperature calculated for the Triassic-Jurassic stromatolites was 32.6°C.

Permian-Triassic stromatolites yielded temperatures of between 87.9 and 122.4°C. The average temperature calculated for the Permian-Triassic stromatolites was 102.5°C.

Discussion: The data from the Triassic-Jurassic stromatolites yield physically plausible ocean temperatures. These stromatolites present evidence for increases in oceanic temperatures coincident with the global climate change leading the Triassic-Jurassic extinction. These preliminary results may indicate that ocean temperatures were increasing locally due to the larger scale global climate change associated with the eruption and sea floor spreading occurring at the Central Atlantic Magmatic Providence.

The data from the Permian-Triassic stromatolites yielded incredibly high temperatures, which cannot represent ocean temperatures. An explanation for these high temperatures is that carbonate that was analyzed was a combination of biogenic and diagenetic phases. In order to test this hypothesis, thin sections of these stromatolites could be analyzed with cathodoluminescence microscopy to differentiate between biogenic and diagenetic carbonate. After differentiation, microdrilling could be used on the biogenic carbonate to obtain more accurate readings of microbialite growth temperatures.

Conclusions:
The plausible ocean temperatures yielded by the Triassic-Jurassic stromatolite samples merit further investigation. Further study of stromatolites across the Triassic-Jurassic boundary could be used to create a better understanding of the changes in climate that occurred, and provide insights into what may have driven the mass extinction..

The Permian-Triassic stromatolites did not yield climatically useful information, possibly due to the mixing of biogenic and diagenetic phases of carbonate. In order to obtain better results in the future, these Permian-Triassic stromatolites will be analyzed using cathodoluminescence microscopy to guide microdrill ing.

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