Lamination-scale geochemistry of microbialites: investigating the combined effects of primary mineralogy and diagenesis in microbialites from the Upper Cambrian and Lower Triassic of the western U.S.

Riley Zheng, Pedro J Marenco and Katherine N Marenco
Department of Geology, Bryn Mawr College

Abstract

Microbialites are important for understanding the history of Earth's changing life and environments. Although macroscopic features of stromatolites have received extensive study, considerably less research has focused on lamination-sale differences in elemental and isotopic composition with the goal of understanding the role of diagenesis in the preservation of geochemical signals. Here we report preliminary results from three microbialite samples—one from the Lower Triassic and two from the Upper Cambrian—that reveal lamination-scale differences in diagenetic alteration resulting from primary lithologic features.

The Early Triassic microbialite was collected from the Virgin Limestone Member of the Moenkopi Formation, Nevada, USA. These limestone stromatolites are characterized by alternating dark and light brown laminations. The light brown layers have lower Sr/Mn ratios (~2), lower $\delta^{13}C$ compositions (average -1.5 ‰ VPDB), elevated abundances of quartz, and increased secondary porosity. In contrast, the darker layers show heavier $\delta^{13}C$ compositions (average +0.4 ‰ VPDB), higher Sr/Mn ratios (~7), an absence of quartz, and lower porosity. Differences in depositional lithology likely led to increased diagenetic alteration in the light brown laminations compared to the dark brown laminations.

Two Late Cambrian microbialite samples were collected from the Hellnmaria Member of the Notch Peak Formation, Utah, USA. These dolomitic samples exhibit poor stromatolitic lamination consisting of alternating light brown and dark black layers. In both samples, $\delta^{13}C$ compositions are uniform between layers and fall between 0.3‰ and 0.9‰ VPDB. Sr/Mn ratios are also uniform between the layers (~0.5). It is possible that laminations were lithologically similar to begin with such that dolomitization altered both the light brown and dark black laminations to a similar extent.

Although preliminary, our results highlight the impact of primary lithology on diagenetic alteration of microbialites. Similarly, they highlight the importance of the impact of diagenesis on paleoenvironmental proxies in microbialites. Further study of lamination-scale geochemistry will allow for a better understanding of paleoenvironmental conditions of microbialite formation and preservation.

Methods

Samples were cut and polished so that light and dark laminations could be readily distinguished. Laminations were then categorized based on color and drilled under a microscope using a hand-held dental drill with a diamond-coated bit. Multiple shallow drill holes were made to produce approximately 5mg of powder. Approximately 3mg of powder were dissolved with 10% phosphoric acid for $\delta^{13}C$ analysis on a Picarro Cavity Ring Down Spectrometer. Approximately 2mg of powder were dissolved in 2% trace metal grade nitric acid for elemental analysis on an Agilent ICP-MS. A separate set of powders was generated by combining drilled powder from multiple laminations of each type to generate enough material for XRD analysis.

Results

The Lower Triassic microbialites (LCSB) are characterized by alternating dark and light brown laminations. The light brown laminations exhibit lower Sr/Mn ratios (average = 2) and lower $\delta^{13}C$ values (average = -1.5 ‰ VPDB) while the dark layers exhibit higher Sr/Mn ratios (average = 7) and higher $\delta^{13}C$ values (average = +0.4‰ VPDB) (Fig 1&2). In addition, light layers were softer to drill, exhibited higher visible porosity, and contained elevated quartz abundance according to the XRD results (Fig 4). The Upper Cambrian microbialites (LAW4.5 & 7.5) are predominantly dolomite for both light and dark layers (Fig 6&7). In both Upper Cambrian samples, $\delta^{13}C$ values exhibit little variation between layers (values range between 0.3‰ VPDB and 0.9‰ VPDB) (Fig 1). Similarly, Sr/Mn ratios also exhibit little variation between layers (average = 0.51 with standard deviation of 0.07) (Fig 2). These general trends can also be discerned from Figure 2 with the values of the LAW samples clustering at the high $\delta^{13}C$ and low Sr/Mn corner and the values of the LCSB samples showing distinctive grouping of different laminations (light layer samples cluster near the low $\delta^{13}C$, low Sr/Mn corner, while the dark layer samples cluster near the high $\delta^{13}C$, high Sr/Mn corner).

The elemental analysis shows similar trends with respect to cobalt and nickel (Fig 3). Although there are several outliers, the data of the Upper Cambrian samples (LAW4.5 & 7.5) cluster together at the low cobalt and nickel corner. The Lower Triassic data (LCSB) shows separate grouping of the dark and light layers: the darker layers exhibit lower cobalt and higher nickel abundance while the lighter layers exhibit higher cobalt and lower nickel abundance.

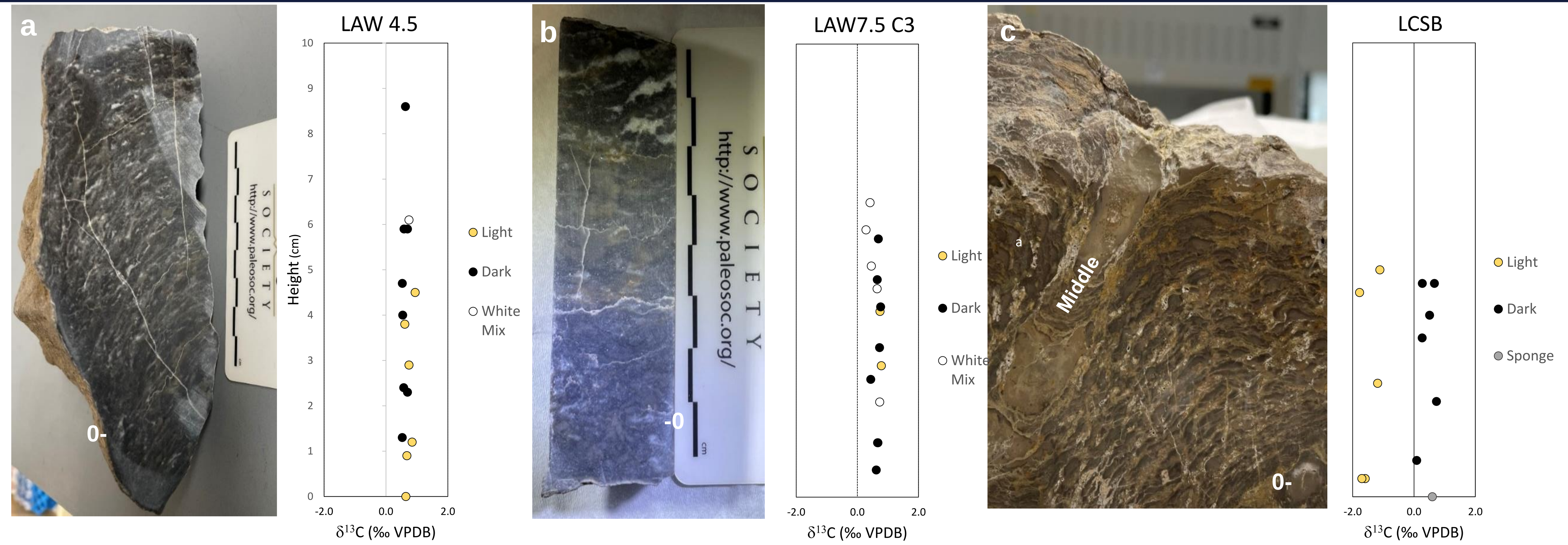

Fig 1. Photographs of micro-drilled surfaces and corresponding $\delta^{13}C$ data. a) The cut surface of a microbialite collected from float about 4.5m from the base of the exposed Upper Cambrian Notch Peak Formation at Lawson Cove, Utah (LAW4.5). b) The cut surface of a drill core taken from a microbialite collected from float about 7.5m from the base of the Lawson Cove section (LAW7.5 C3). c) The cut surface of a Lower Triassic (Spathian) microbialite collected in-situ from about 155m from the base of the exposed Virgin Limestone Member of the Moenkopi Formation at Lost Cabin Springs, Nevada (LCSB).

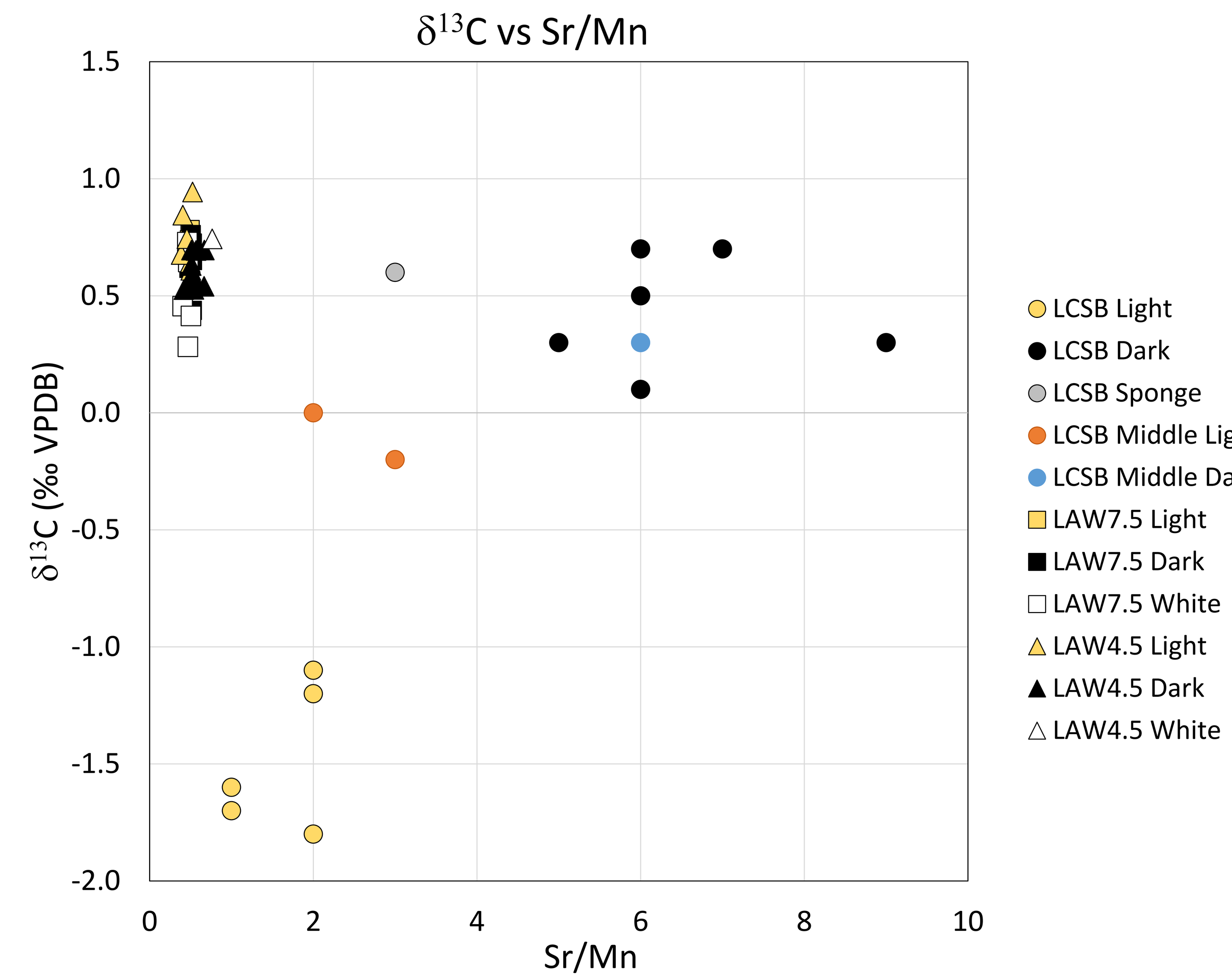

Fig 2. Cross plots of $\delta^{13}C$ values versus Sr/Mn ratios within the three analyzed microbialite samples. Data from the Upper Cambrian microbialites are plotted as squares and triangles whereas data from the Lower Triassic microbialite are plotted as circles.

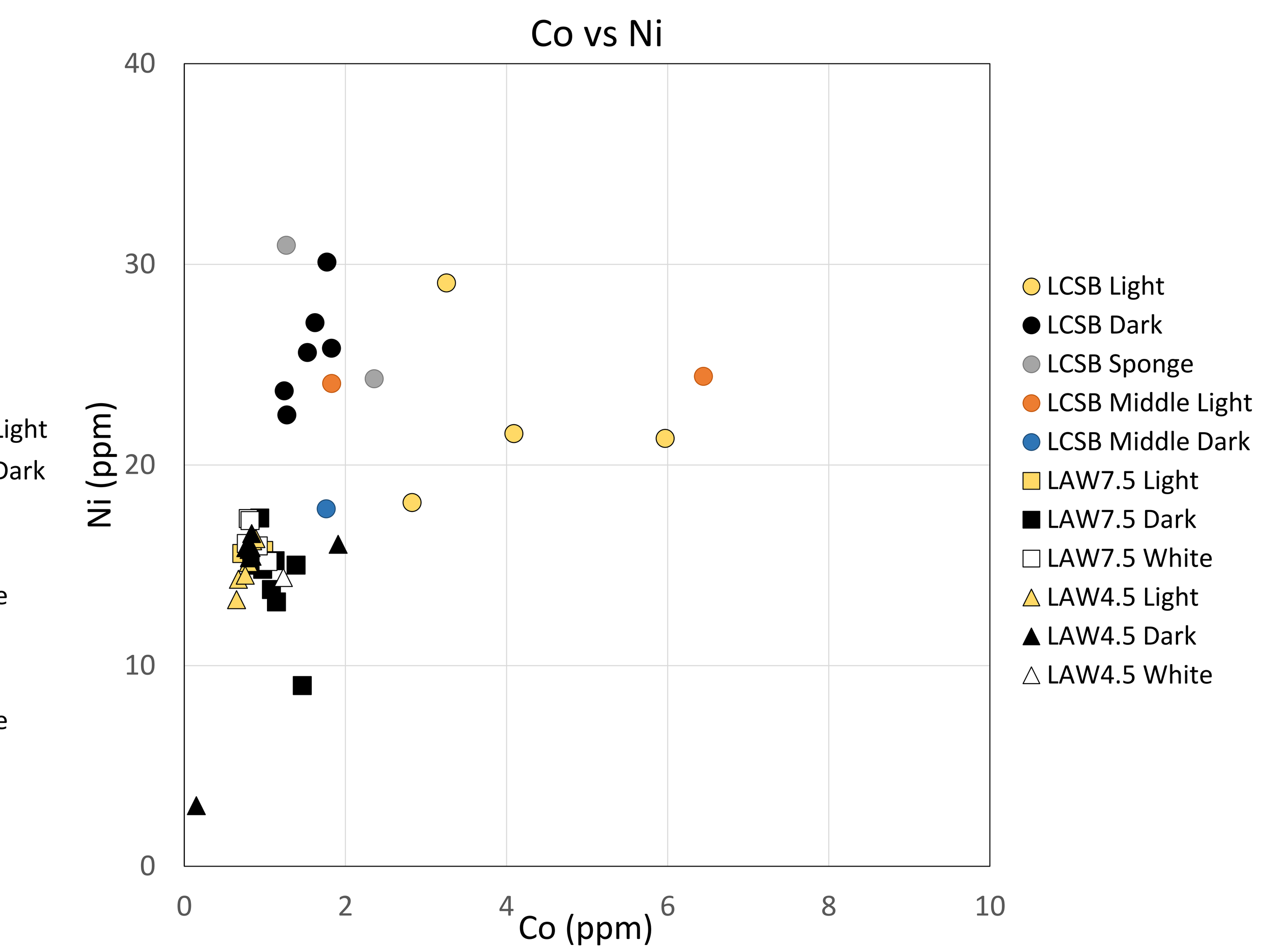

Fig 3. Cross plots of cobalt versus nickel abundance within the three analyzed microbialite samples. Data from the Upper Cambrian microbialites are plotted as squares and triangles whereas data from the Lower Triassic microbialite are plotted as circles. One outlier with a nickel abundance of 68ppm from the light lamination of the Lower Triassic LCSB sample is not shown on the graph.

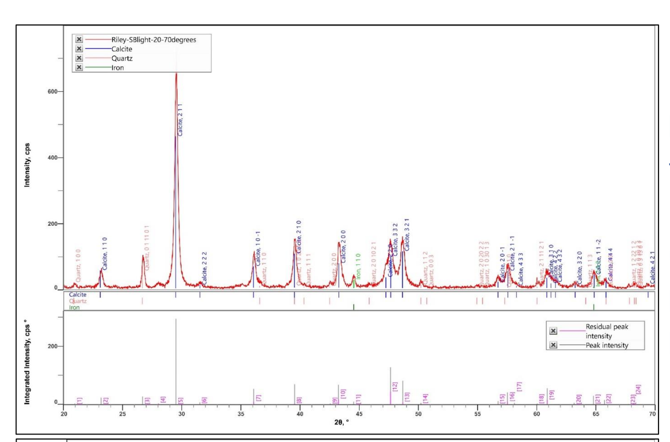

Fig 4. XRD plot of the lighter laminations from the Lower Triassic LCSB sample showing calcite peaks labeled in purple and quartz peaks labeled in pink.

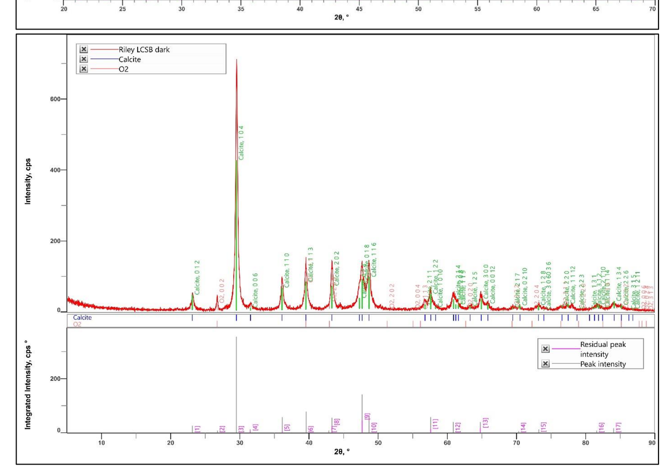

Fig 5. XRD plot of the darker laminations from the Lower Triassic LCSB sample showing calcite peaks labeled in green.

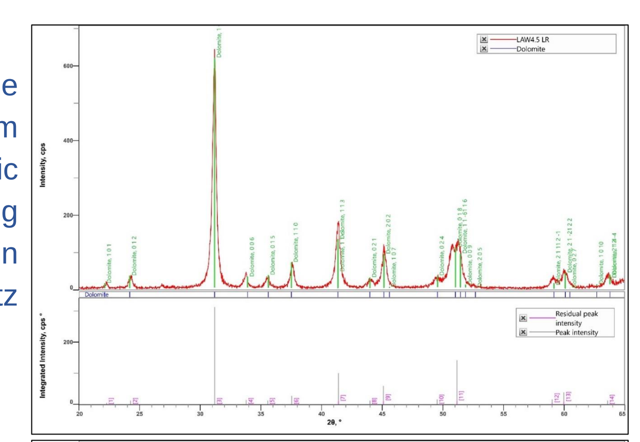

Fig 6. XRD plot of the lighter laminations from the Upper Cambrian LAW4.5 sample showing dolomite peaks labeled in green.

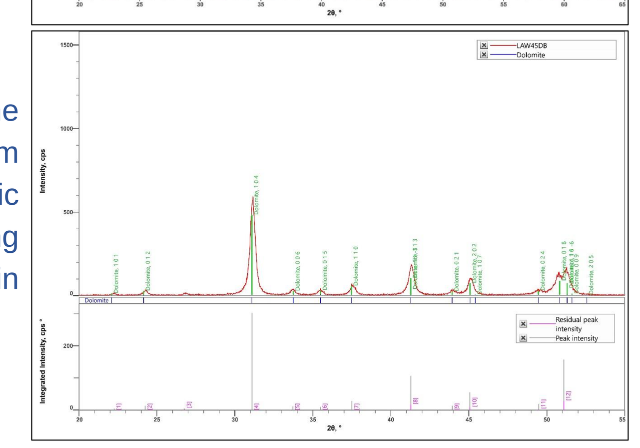

Fig 7. XRD plot of the darker laminations from the Upper Cambrian LAW4.5 sample showing dolomite peaks labeled in green.

Discussion

Based on the distinctive groupings in elemental and isotopic results from the Lower Triassic microbialite (LCSB), it is likely that primary mineralogic composition as well as diagenetic alteration contributed to the differences in geochemical composition between the darker and lighter laminations. The higher abundance of quartz and increased porosity of the light laminations indicate a different primary mineralogic composition than that of the dark laminations. The lower Sr/Mn ratios of the light layers strongly suggest that these layers were more diagenetically altered than the dark layers.

The association of lower $\delta^{13}C$ values with the lighter laminations could either reflect increased diagenetic alteration or primary differences associated with decreased microbial mat activity during times of higher ambient sedimentation. Photosynthesis associated with microbial mats would likely remove light carbon from the localized dissolved inorganic carbon pool, leaving dissolved inorganic carbon heavier. Thus, the lower $\delta^{13}C$ values of the lighter layers may reflect an increased abundance of ambient carbonate sediments relative to in-situ, mat-induced carbonate cements. Whether or not changes in microbial mat activity were involved, the lower Sr/Mn ratios suggest that some amount of diagenetic alteration took place.

In contrast, the homogenous results from the Upper Cambrian microbialites suggest a different story. Although both groups of laminations exhibit extensive diagenetic alteration via dolomitization, aside from subtle variations in color there is little to suggest that the laminations reflect significant differences in the original mineralogy. The homogeneity in the geochemical results can either reflect overprinting of original geochemical compositions by diagenesis or relative continuity of microbial mat activity under low levels of ambient sedimentation.

Conclusions

- Lamination-scale geochemistry has the potential to help us understand short-term environmental changes during the accumulation history of a microbialite.
- Different microbialites have different diagenetic trajectories based on original mineralogic compositions.
- Diagenesis should be carefully considered when addressing lamination-scale geochemistry and mineralogy.

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