Revised contemporary lacustrine carbonate temperature lapse rate for southwestern North America

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Abstract

The creation of a paleo-altimeter has the possibility to revolutionize the way in which Earth's tectonic history is studied. As the paleotemperature of carbonates can now be directly found with the carbonate 'clumped' isotope thermometer (eg, Eiler 2006), determining the relationship between temperature and elevation in carbonates is the keystone to turning the clumped isotope thermometer into an altimeter. A recent study by Huntington et al. (2010) investigated the lapse rate (change in temperature divided by change in elevation) of modern lacustrine carbonates using the clumped isotope thermometer. This study demonstrated that:

1) Both lacustrine carbonate temperatures and lake surface temperatures show a negative lapse rate (ie, lake temperatures drop as elevation increases)

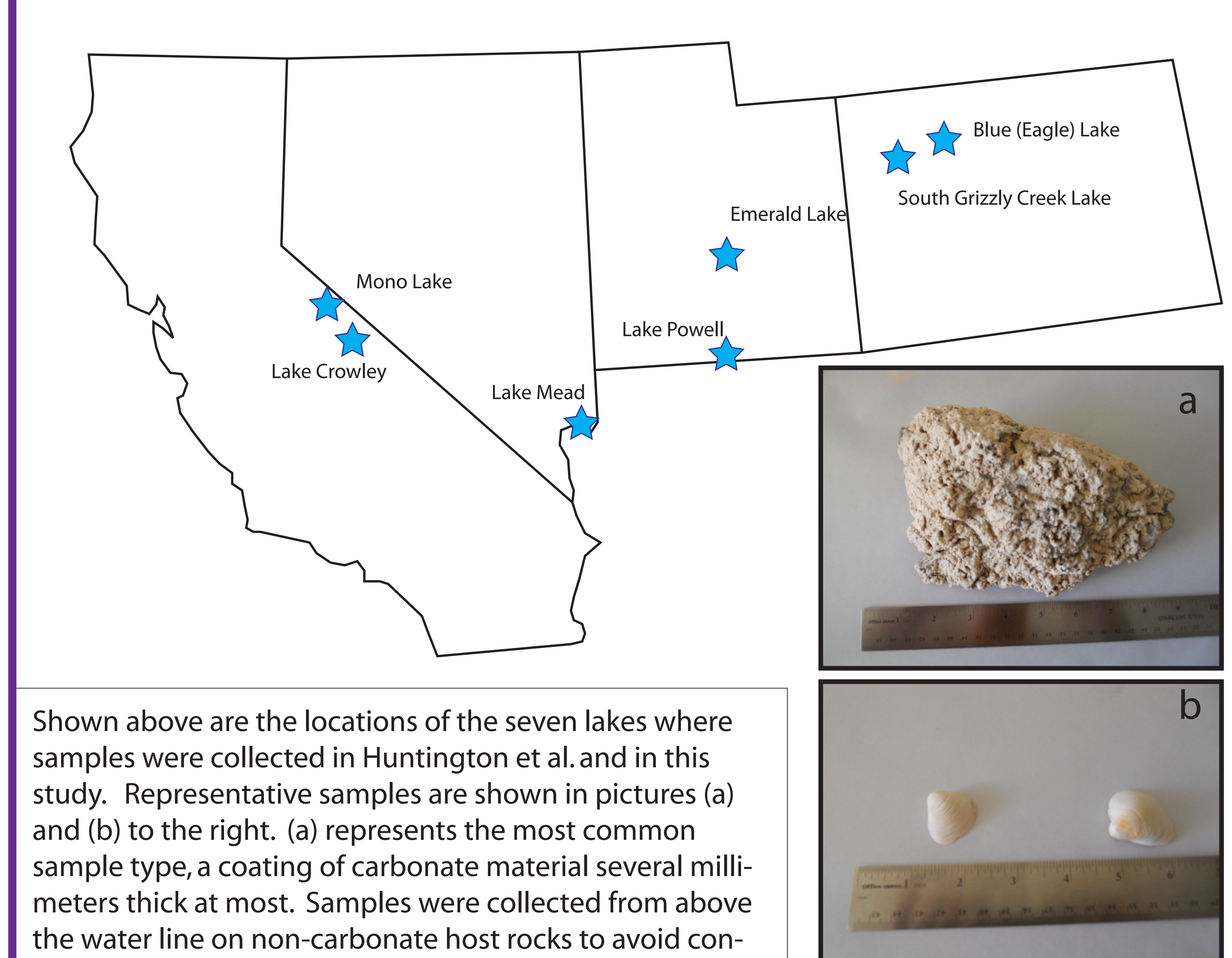
2) The average carbonate temperatures fall between the average winter and summer lake surface temperature values.

3) Modern carbonates have a large spread in possible values, indicating that they likely formed in the temperature-fluxuating surface water, rather than in the temperature-constant deep water of large lakes.

4) The carbonate lapse rate is notably shallower than the surface water lapse rate, having a value of -4.2 C/km rather than a value of either -4.8 C/km (winter average) or -5.6 C/km (summer average).

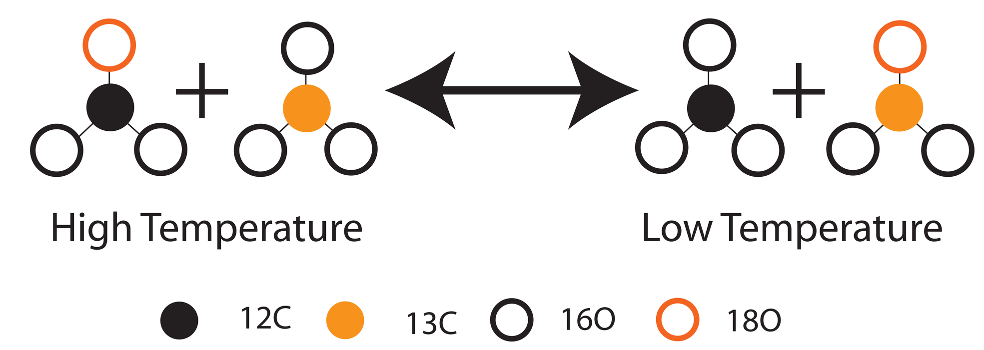
Here we test this lapse rate by analyzing additional modern lake samples from Lakes Mead and Powell, and find that the lacustrine carbonate lapse rate is better fit with a value of -5.4 C/km. We also investigated the amount of variability between samples of modern carbonate taken from different locations in the same lake, and found all the samples to show large amounts of variability. However, when compared to lake surface temperature variability data summarized by Huntington et al, we find that the variation in the carbonate material is similar to the variability seen in the lake surface temperatures.

Samples



Shown above are the locations of the seven lakes where samples were collected in Huntington et al. and in this study. Representative samples are shown in pictures (a) and (b) to the right. (a) represents the most common sample type, a coating of carbonate material several millimeters thick at most. Samples were collected from above the water line on non-carbonate host rocks to avoid contamination. (b) is a picture of one of the shells collected.

Methods



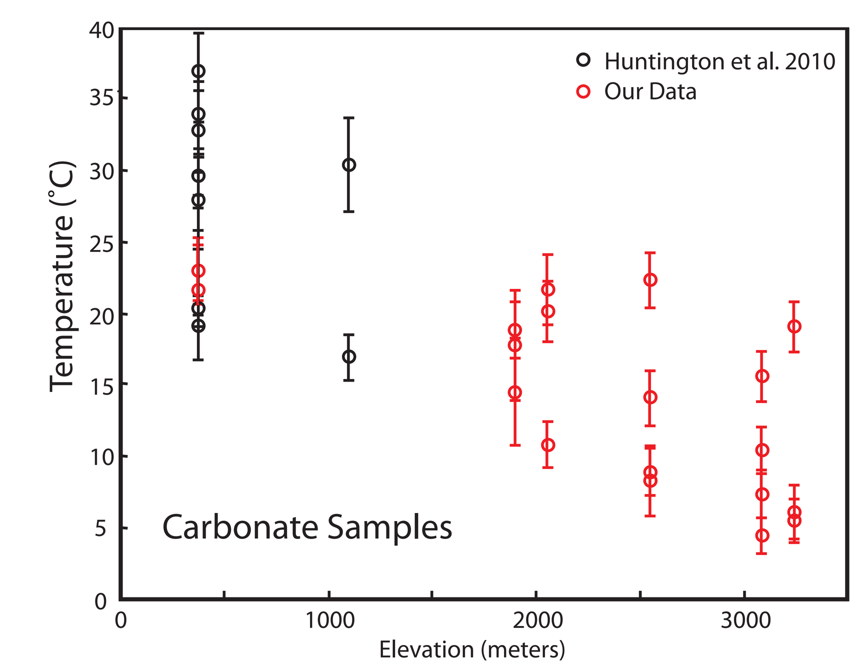
$$Ca^{13}C^{16}O_3 + Ca^{12}C^{18}O^{16}O_2 \leftrightarrow Ca^{13}C^{18}O^{16}O_2 + Ca^{12}C^{16}O_3$$

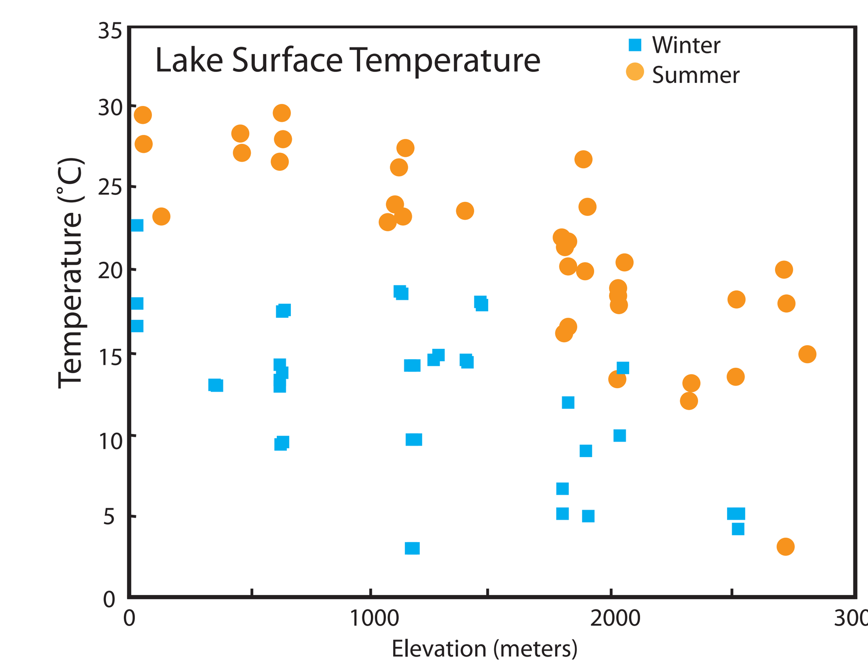
The carbonate clumped isotope themometer determines the temperature of a carbonate sample based on the relative 'clumping' of heavy isotopes into doubly substituted carbonate molecules. The thermodynamic arguement is as follows. Clumping is favorable at low temperatures, while at high temperatures there is no preference towards clumping. In our samples, the clumped ratio of interest is D47, the deviation of the sample's mass 47 CO2 measurement from a stoichastic (statistically random) mass 47 CO2.
Our samples were prepared by drilling 10 milligrams of carbonate varnish per 'sample.' These samples were individually introduced to phosphoric acid held at a constant 90˚C, which reacted with the carbonate and released CO2 gas. There is a known correction factor between the carbon dioxide D47 and the D47 of the carbonate sample. The sample was then filtered and cleaned through repeated condensation of the CO2. We then introduce this purified gas into the mass spectrometer, with each sample having 8 acquisitions which in turn have 8 individual measurements of the D47 of the CO2 gas. These data can then be transformed into a temperature measurement using an empircal temperature-D47 relation, in our case by Ghosh 2006:

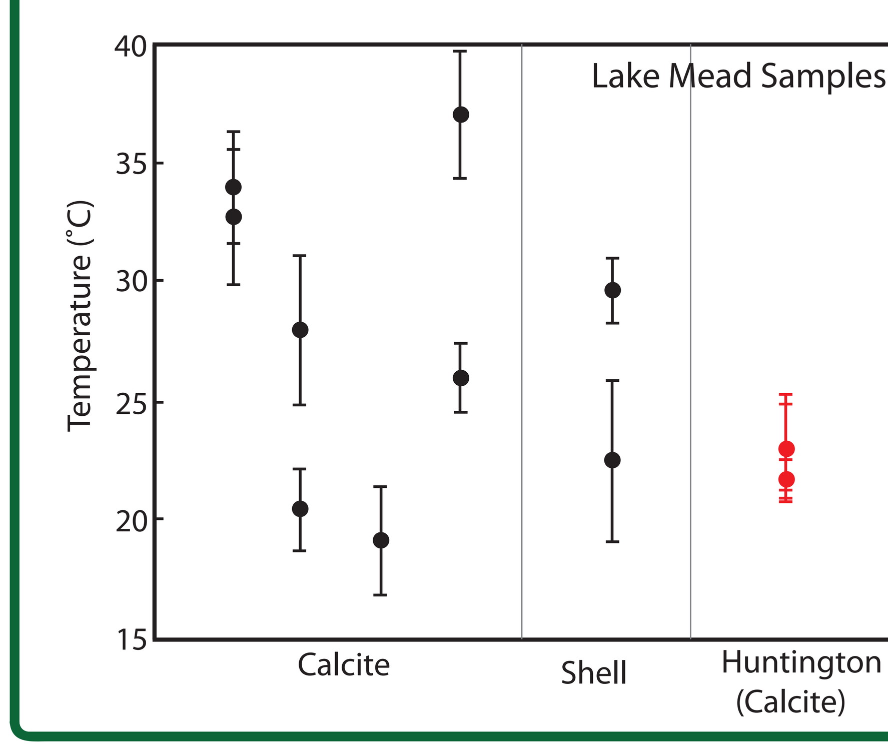
$$D47=59200*T^{-2}-0.02$$

All error measurements in plots shown here are 1-sigma standard error as our samples are means of many acquisitions. Replicates of samples were also run to ensure that the temperatures found were representative values.

Sample Variability



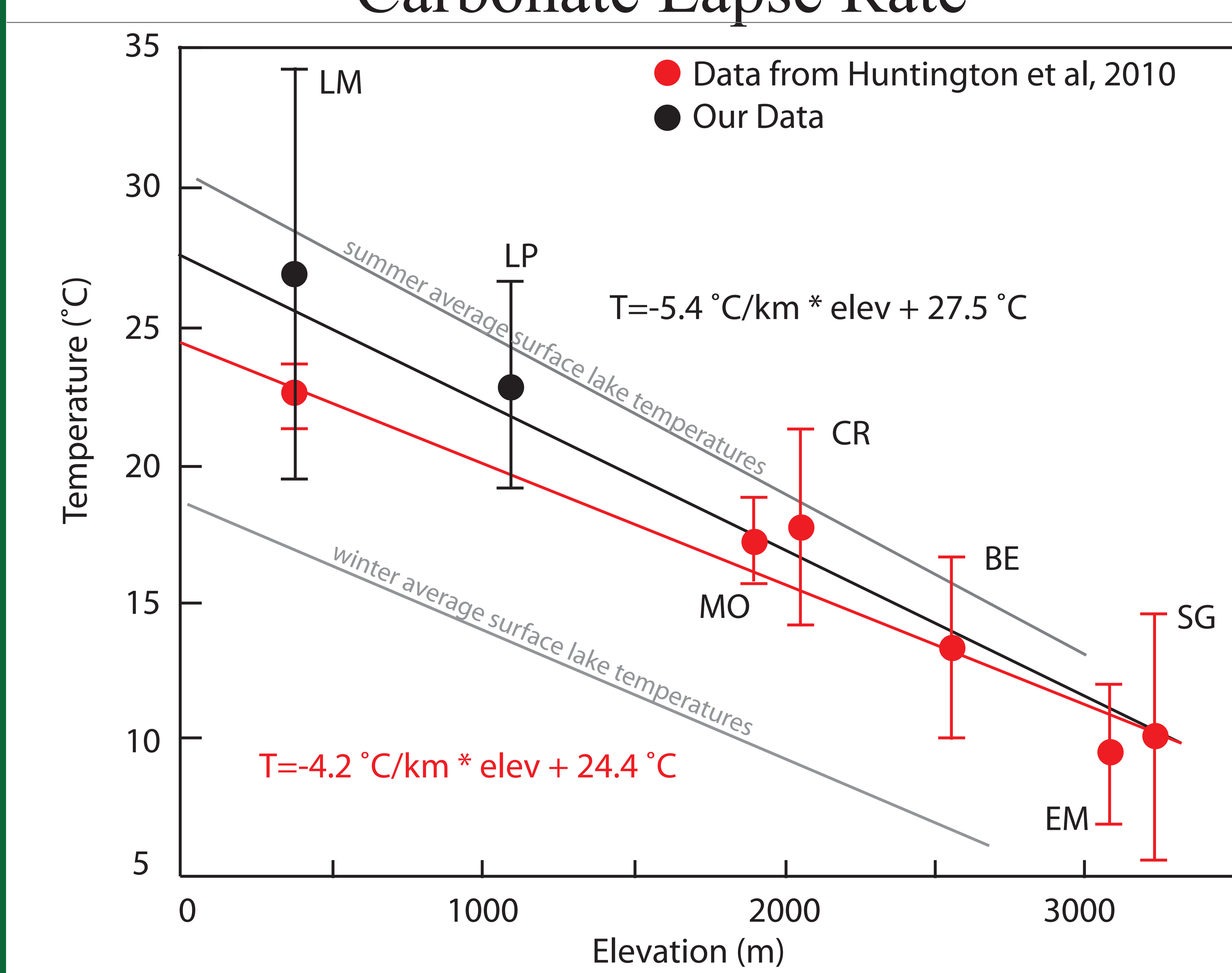




Above: The left plot shows all of the sample replicate data used to calculate our carbonate lapse rate, from which the average values were taken to find the lapse rate. The variability in the samples is to be compared to the right plot, which shows the range of values in monthly average surface lake water temperatures from lakes in the Western United States. This figure is adapted from Huntington et al 2010. The variability in the two figures is similar, suggesting that the carbonates are a faithful record of lake surface temperatures.

Left: Individual replicates of samples taken for Lake Mead. The horizontal axis demarks replicates from the same sample. Some sample replicates are fairly similar in temperature, while others are very markedly different, but the range is similar in magnitude to the lake surface temperatures shown above, suggesting that the carbonates are recording a seasonal temperature.

Carbonate Lapse Rate



Plot of the lake averages for our data (black) and data from Huntington et al (red). All averages are representative of a single sample, save for our data from Lake Mead, which incorporates data from 3 varnish samples and 1 shell sample (see Variablity section for more details). Lines representing the lapse rates of summer and winter averages are taken from Huntington et al. With our data added, a regression through all sample averages results in a lapse rate of -5.4 ˚C/km, which is subparallel to the lapse rate expected from the summer average lake surface temperature (-5.6 ˚C/km). This strongly suggests that lacustrine carbonate material can be used as an idicator of paleo-elevation if the samples are not thermally reset, and if the 0 elevation temperature can be determined from sea-level lake carbonates. Abbreviations refer to lake name.

Conclusions

* With our added data, the lacustrine carbonate temperature lapse rate is found to be more closely related to the lake surface temperature lapse rate than previously determined.
* The magnitude and range of temperature variability is similar to that of lake surface temperature record. Large variability in the recorded temperatures is not an artifact of the clumped isotope thermometer but is reflects real variability in the carbonate record.
* The values of our samples average only a few degrees below what the summer average of lake surface temperatures is, suggesting that the majority, but not all, of lacustrine carbonate material is formed in the summer months.
* The carbonate lapse rate of Huntington et al (2010), while now modified in exact value, fit our new data from Lake Mead and Lake Powell. This is a favorable result for future studies attempting to use a lacustrine carbonate lapse rate to approximate paleo-elevation, assuming the lapse rate has not changed through time.

References and Acknowledgements

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Ghosh, P., J. Adkins, H. Affek, B. Balta, W. Guo, E. Schauble, D. Schrag, and J. Eiler (2006), 13C-18O bonds in carbonate minerals: A new kind of paleothermometer, Geochim. Cosmochim. Acta, 70, 1439-1456.

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