Cave Deposits in Minnesota Reveal Climate Changes over Last 8000 Years

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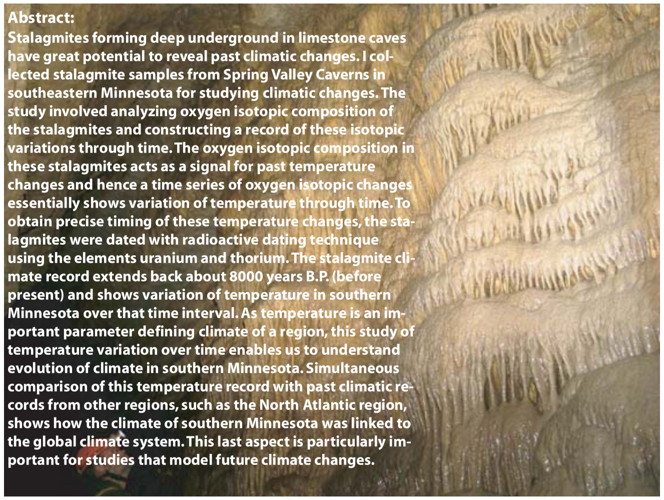


Abstract:
Stalagmites forming deep underground in limestone caves have great potential to reveal past climatic changes. I collected stalagmite samples from Spring Valley Caverns in southeastern Minnesota for studying climatic changes. The study involved analyzing oxygen isotopic composition of the stalagmites and constructing a record of these isotopic variations through time. The oxygen isotopic composition in these stalagmites acts as a signal for past temperature changes and hence a time series of oxygen isotopic changes essentially shows variation of temperature through time. To obtain precise timing of these temperature changes, the stalagmites were dated with radioactive dating technique using the elements uranium and thorium. The stalagmite climate record extends back about 8000 years B.P. (before present) and shows variation of temperature in southern Minnesota over that time interval. As temperature is an important parameter defining climate of a region, this study of temperature variation over time enables us to understand evolution of climate in southern Minnesota. Simultaneous comparison of this temperature record with past climatic records from other regions, such as the North Atlantic region, shows how the climate of southern Minnesota was linked to the global climate system. This last aspect is particularly important for studies that model future climate changes.

SECTION 1:

BACKGROUND ON ISOTOPES, FORMATION OF STALAGMITE AND INCORPORATION OF CLIMATE SIGNAL INTO IT

Water is made of Hydrogen (H) and Oxygen (O) atoms. Oxygen can exist in water as ^{18}O and ^{16}O (the numbers refer to their masses) called isotopes of oxygen. Of these ^{18}O is heavier and ^{16}O is lighter.

When rain forms from cloud then the temperature at which the rain forms controls how much ^{18}O and ^{16}O will go into the rain (Fig. 2).

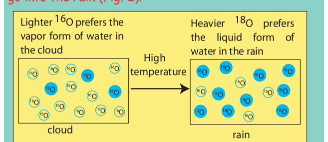


Fig. 2

If the temperature is high then more ^{18}O will go into the rain than ^{16}O.

Hence, rainwater with high $^{18}O/^{16}O$ ratio will mean that this rain formed at high temperature.

So if there is something, which can store rainwater information through time then analysis of this rainwater will give us information on the temperature. Stalagmites from high latitude caves can store information about past rainfall and its temperature.

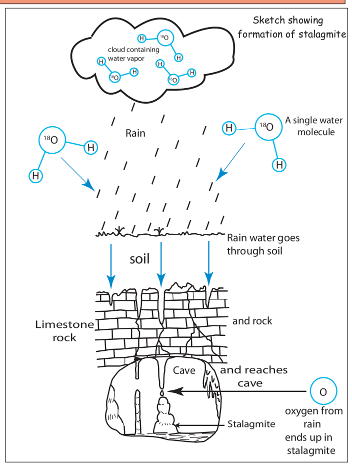


Fig. 1

How does a stalagmite form?

Rain water mixes with carbon dioxide in the soil, becomes acidic and dissolves the limestone when passing through it. Rain water then carries the dissolved limestone with it to the cave below. In the cave the water carrying the dissolved limestone can no longer carry the limestone in the dissolved state and hence deposits it.

The different cave deposits we find in a cave are formed this way. For our study we use stalagmites, which are column like structure growing up from the cave floor (Fig. 3).

The temperature of the cave typically corresponds to the average annual temperature of the ground above the cave. During deposition of the stalagmite the ambient temperature of the cave determines the amount of ^{18}O and ^{16}O that will go into the stalagmite.

We study the ratio of the two oxygen isotopes i.e. $^{18}O/^{16}O$ and see how this ratio varies through time. If the mean annual temperature above the cave changes due to climatic change, the cave temperature will also change and hence the $^{18}O/^{16}O$ ratio will also change.

Stalagmites

Fig. 3

Stalagmites grow slowly year by year, forming layers as they grow (Fig. 4).

Each layer will preserve a $^{18}O/^{16}O$ ratio which will reflect the temperature of formation of that layer.

In the next section we show how we study the isotopes in the stalagmites and obtain past climate information.

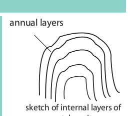
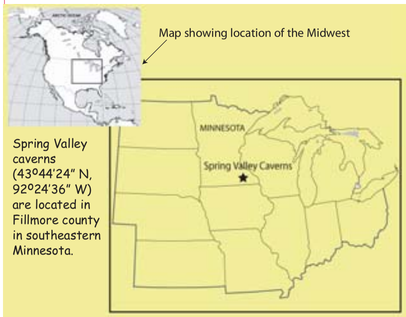


Fig. 4

SECTION 2:

LOCATION, SAMPLE PREPARATION AND ANALYTICAL METHODS



Spring Valley caverns (43º44'24" N, 92º24'36" W) are located in Fillmore county in southeastern Minnesota.

Fig. 5

The samples were collected from a narrow passage inside the cave (Fig. 6). The passage is located more than sixty feet below the ground.

This type of deep cave ensures no interaction with the outside and so the signal in the stalagmite can be trusted to be unaltered.

The tall stalagmite is about 60 cm in length.

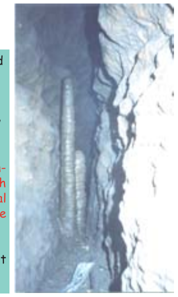


Fig. 6

How do we know the ages of stalagmites or in other words, how do we date the stalagmites?

When a stalgmite is deposited then very tiny amounts of the element uranium (U) gets incorporated into it. This U is radioactive (not stable) and decays to other elements over a long period of time, producing what is called a decay chain. The final product of this decay chain is ^{208}Pb (Lead). For our work we focus into a part of the decay chain where ^{234}U decays to ^{230}Th (thorium) over time. As time passes more and more thorium builds up. This breakdown of U into Th is related mathematically, such that if we can measure the amount of U and Th present now, we can calculate how much time has passed since the deposition of the stalagmite.

$$^{238}U \longrightarrow \ldots\ldots \longrightarrow {}^{234}U \longrightarrow {}^{230}Th + \text{energy} \longrightarrow \ldots\ldots \longrightarrow {}^{208}Pb$$

As U and Th are present in very small amounts, we measure them with the help of specialized machines known as mass spectrometers, which can precisely measure very tiny amounts of elements. In the Minnesota isotope lab, I used a highly specialized mass spectrometer called ICP-MS (inductively coupled plasma mass spectrometer) to measure U and Th in my samples and then calculated the ages. Fig. 8 shows the dates obtained from one of the stalagmites. These dates are very precise (average error is about 3%) enabling reconstruction of very high resolution records from the stalagmites.

In the lab we cut and polish the samples and then drill powders for the purpose of dating and measuring oxygen isotopes.
The figures show polished section of stalagmites and drill holes for dates and isotopic measurements (Fig. 7a & b).

Fig. 7a

Polished section of stalagmite

Fig. 7b

Polished section of stalagmite showing ages at different layers

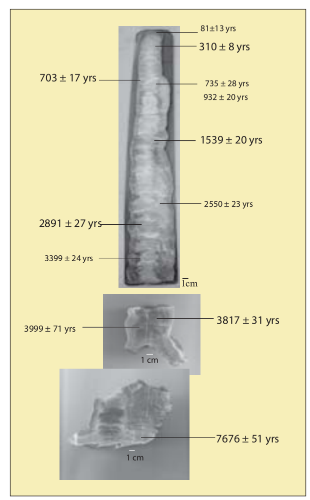


Fig. 8

SECTION 3:

RESULTS, DISCUSSION AND CONCLUSIONS

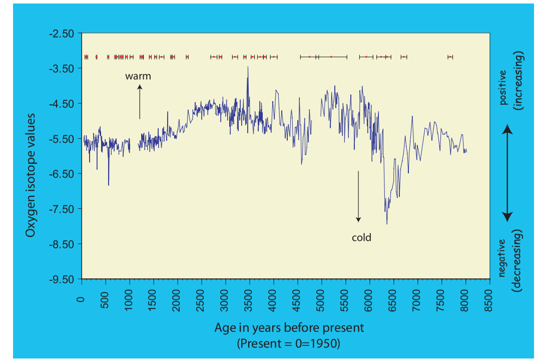


Fig. 9

In this figure (Fig. 9) measured oxygen isotopic values are plotted along the y axis and age is plotted along the x axis. The age is reported as number of years before 1950, as a convention. This figure shows how the oxygen isotopic composition of the Spring Valley stalagmites varied through time. The red dots with black lines on the top show the dates and their associated errors.

As explained in Section 1, we will interpret the positive (increasing values) and negative (decreasing values) shifts of the oxygen isotopic composition in terms of warming and cooling trends respectively.

In our record we observe that Minnesota was in general warmer than today from about 8000 to 2500 years back. But there were a few cold events, which punctuated the warm interval. These are centered at 6300, 4500 and 520 years back. We also observe two sharp warming events centered at 3500 and 4000 years back.

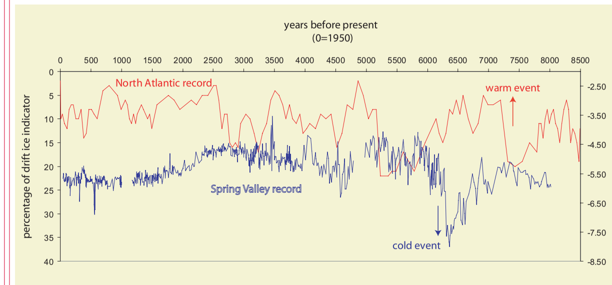


Fig. 10

In order to understand how climate evolves through time and the causes of climate changes, it is necessary for us to compare past climate records from different areas. As an example, I present one such comparison between the Spring valley record and an ocean core record from the eastern North Atlantic Ocean (Bond et al., 2001, *Science* 294), (Fig. 10). This ocean core record shows variation of drift ice through time. An increase in the drift ice indicator means a cold event in the North Atlantic and vice versa.

We observe that before ~2500 years cold events in the North Atlantic coincided with warm events in the Midwest. This observation points to a cold ocean-warm land type situation during certain times in the past. From modern observations (http://www.arctic.noaa.gov/detect/climate-strat.shtml) we know that this type of situation is brought about by some specific changes in the atmospheric circulation pattern. Comparison of these two records suggests that similar atmospheric patterns might have occurred in the past.

Conclusions:

Stalagmites are capable of producing very high resolution records of past climate changes as they can be dated very precisely.

The Spring Valley record is interpreted as a warming/cooling record and it shows how the climate evolved over the past 8000 years in southern Minnesota

Comparison of Spring Valley record with North Atlantic Ocean record shows opposing climate pattern in the two regions.p

This type of high resolution climate record provides information about the earth's climate at a time when ice sheets were not present. As this situation is similar to present day, these past high resolution records can provide valuable insights for modelling future climate.