Interpreting past climates using carbon-oxygen isotopes with emphasis on stalagmites

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Abstract

Carbon-oxygen isotopic applications are generally used to help scientists learn about past environments. One such implementation is accomplished by studying the $\delta^{13}C$ and $\delta^{18}O$ values of stalagmites. Stalagmites, which typically grow in layers or laminations in caves, provide valuable information about the environment that exists above their deposits. The most important controls of stalagmite growth are the CO_2 saturation of drip water relative to the cave atmosphere, temperature and the flux of water (Mariethoz et al. 2012). This report studies several examples of stalagmite growths, as well as a related example that highlights carbon-oxygen isotopic compositional factors, and attempts to show a wide range of utilities in studying stalagmites, as well as other speleothems, in the study of paleoclimatology. Additionally, this report offers a brief summary of some of the shortcomings in current stalagmitic research methods and areas in which improvements can be made.

Introduction

Carbon and oxygen isotopes provide many tools in interpreting past climates. Paleoclimatology, paleotemperatures, paleoproductivity, circulation patterns, and water depth are just a few of the notable applications available (Sharp, 2007). This report focuses primarily on the first three methods and derives its data from five studies where the emphasis is on speleothems. Mariethoz et al. (2012) examine annual growth rate data from eleven stalagmites located on four continents and used geostatistical tools to better understand the differences caused from local and global factors. Stevenson et al. (1999) look at a well-dated, uninterrupted, aragonite stalagmite and report carbon and oxygen isotope ratios from the Cold Air Cave in Makapansgat Valley, Northern Province, South Africa. In their report, Tyson et al. (2000) also studied a stalagmite in the Cold Air Cave. Using $\delta^{18}O$ and $\delta^{13}C$ values, Tyson et al. (2000) attempted to associate the region with historic global phenomenons, such as the postulated Little Ice Age. Lamb et al. (1999) examine the carbon and oxygen isotope record of authigenic calcites in a core from Lake Tilo, a crater lake in the Ethiopian Rift Valley, which provides a sub-century scale record of lake feedback to climate change.

Tan et al. (2006) acknowledge the complimentary benefits by studying tree rings, which are typically quite useful in preserving seasonal climatic indicators on a sub-centennial scale, with stalagmite laminations, which is useful in preserving multi-centennial climate signals, but can be constrained by mixing of ‘event’ water with ’stored’ groundwater. They admit that studies based on stalagmite layers is not widely utilized, partially due to a lack of an established methodology and difficulty in finding long annually laminated records.

Results

Tyson et al. (2000) established $\delta^{18}O$ variations that experienced their greatest depletions between the fourteen and nineteenth centuries (Figure 1). The lowest of these values occurred at roughly around 1700. These results are supported by carbon isotopes and colour variations in banded growth laminations. The data collected by Stevenson et al. (1999) displayed similar $\delta^{18}O$ depletion with a high-amplitude depletion occuring around 1700. In their report, Stevenson et al. posited a positive relationship between temperature increase and the $\delta^{18}O$ increase.

The range of carbon and oxygen isotope values at Lake Tilo are among the highest recorded for a Holocene core (Lamb et al. 2000). Both isotopes range by 15‰ ($\delta^{18}O$ = -5 to +5‰ and $\delta^{13}C$ = -4 to +11‰) (Lamb et al. 2000). They note that there is a contrast between the stable early-Holocene values (mean $\delta^{18}O$ = -0.3 ± 5.3‰ and $\delta^{13}C$ = 1.3 ± 6.9‰, 2σ)

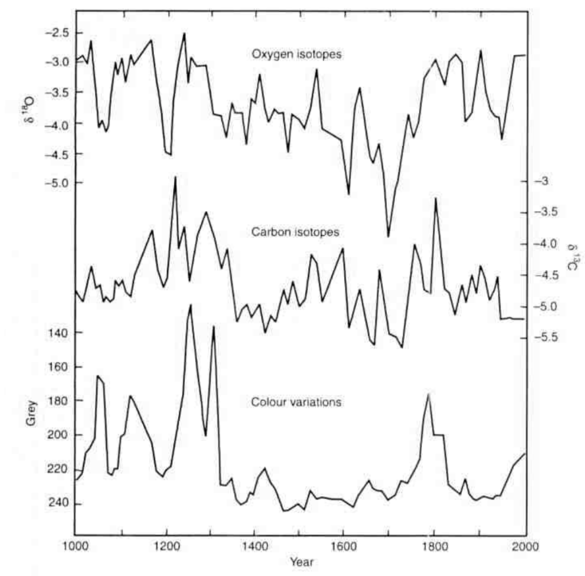

Figure 1. From top to bottom, $\delta^{18}O$, $\delta^{13}C$ and colour variations between 1000 CE and 1996 CE. Colour variation is measured in grey level (Tyson et al., 2000)

The geo-statistical data performed by Mariethoz et al. (2012) showed that studies considering stalagmite laminations will always provide imperfect climate records. This is primarily due to calcite, when deposited, will preserve a record of the year it was deposited and an average of the years preceding it. Their data confirms that there is a trade off between the need for annual lamina to provide precise chronologies and an associated decrease in the strength of low-frequency climate indicators.

Discussion

The studies by Stevenson et al. (1999) and Tyson et al. (2000) seem to confirm that the region of Makapansgat Valley in South Africa did indeed experience a period of cooling, otherwise known as the Little Ice Age. Figure 1 shows a reasonably large drop in colour variation from around 1400 to 1750 CE. $\delta^{13}C$ does show a similar trend, although not as pronounced and with more fluctuations. This seems to correlate with Stevenson et al. (1999), when they suggest that C_4 grasses were less abundant during drier, cooler periods. Although C_4 grasses require less water than C_3 grasses for photorespiration, it seems that aridity is more of a controlling factor in the success of these types of vegetation. As such, the scarcity of vegetation during these periods must ultimately be responsible for the lower colour intensities/$\delta^{13}C$.

Based on their results, Mariethoz et al. (2012) endorse the use of geostatistical analysis of stalagmite growth series. The reason for this is to help quantify the extent and timescale for a possible climate signal might be contained. Tan et al. (2006) add seven further proposals for future studies in order to develop conventions in hopes to increase the desirability of using stalagmite based research of paleoclimatology.

The non-stalagmitic based research for this report provides information on $\delta^{18}O$ and $\delta^{13}C$ values at Lake Tilo. The study shows that a wide range of values occur in this region and provides some insight to why this is the case. According to hydrological estimates based on salinity budget calculations, the crater lake receives ~42% from rainfall, ~8% from run-off from the crater sides, ~38% from local groundwater and finally ~12% from hydrothermal groundwater from a deep volcanic aquifer (Lamb et al., 1999). However, during the Holocene, spring waters and rainfall were the dominate hydrological control which very likely explains the wide range of values.

Conclusion

Although carbon-oxygen applications appear to face challenges, especially when using stalagmite to reconstruct past environments, its utility is no less viable or important. By developing better established conventions and methods, more precise and more correlative data could be obtained. In concert with other methods that can be harnessed in areas of stalagmitic weakness, such as dendrochronology, further advances can be made to take the discipline to even greater precisions and accuracies.

References

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