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# A 53 year seasonally resolved oxygen and carbon isotope record from a modern Gibraltar speleothem: Reconstructed drip water and relationship to local precipitation

David Mattey [a,*], D. Lowry [a], J. Duffet [a], R. Fisher [a], E. Hodge [b], S. Frisia [c]

[a] *Department of Earth Sciences, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK*
[b] *ANSTO Institute for Environmental Research, Lucas Heights, PMB 1, Menai, NSW 2234, Australia*
[c] *School of Environmental and Life Sciences, University of Newcastle, University Drive, Callaghan NSW 2308, Australia*

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**Abstract**

The response of a climate proxy against measured temperature, rainfall and atmospheric circulation patterns at sub-annual resolution is the ultimate test of proxy fidelity but very few data exist showing the level of correspondence between speleothem climate proxies and the instrumental climate record. Cave sites on the Gibraltar peninsula provide a unique opportunity to calibrate speleothem climate proxies with the longest known available precipitation isotopes and instrumental records. An actively growing speleothem sampled from New St. Michaels Cave in 2004 is composed of paired laminae consisting of light columnar calcite and a darker microsparitic calcite. Stable isotope analysis of samples micromilled in 100 μm steps at the equivalent of bi-monthly intervals reveals fabric-correlated annual cycles in carbon isotopes, oxygen isotopes and trace elements responding to seasonal changes in cave microclimate, hydrology and ventilation patterns. Calcite $\delta^{13}$C values reach a minimum in the light columnar fabric and evidence from trace element behaviour and cave monitoring indicates that this grows under cave 'winter' conditions of highest $p$CO$_2$, whereas the dark microsparitic calcite, characterised by elevated $\delta^{13}$C and $\delta^{18}$O values grows under low 'summer' $p$CO$_2$ conditions. Drip water $\delta^{13}$C$_{DIC}$ reaches a minimum in March–April, at which time the attenuated $\delta^{18}$O signal becomes most representative of winter precipitation. An age model based on cycle counting and the position of the $^{14}$C bomb carbon spike yields a precisely dated winter oxygen isotope proxy of cave seepage water for comparison with the GNIP and instrumental climate record for Gibraltar. The $\delta^{18}$O characteristics of calcite deposited from drip water representing winter precipitation for each year can be derived from the seasonally resolved record and allows reconstruction of the $\delta^{18}$O drip water representing winter precipitation for each year from 1951–2004. These data show an encouraging level of correspondence ($r^2$=0.47) with the $\delta^{18}$O of rainfall falling each year between October and March and on a decadal scale the $\delta^{18}$O of reconstructed winter drip water mirrors secular change in mean winter temperatures.


*Keywords:* speleothem; Gibraltar; oxygen isotopes; GNIP; precipitation; seasonality

## 1. Introduction

Speleothem are calcium carbonate deposits which can be precisely dated and provide accurate records of climate change in the past (Henderson, 2006). Studies of oxygen and carbon isotope ratio records have led to significant advances in the understanding of temperature and continental precipitation variability in the last 400,000 years (McDermott, 2004; Fairchild et al., 2005). Nearly all speleothem isotope proxy studies have focussed on long-term change observed at the centennial-millennial scale (e.g. McDermott et al., 2001; Yuan et al., 2004) but the climate driven responses of oxygen isotope time series recorded in speleothem remain largely untested against modern

* Corresponding author.
*E-mail address:* mattey@gl.rhul.ac.uk (D. Mattey).

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instrumental records. Several studies have tested the correspondence between the isotopic composition of precipitation and seepage waters over short periods (e.g. Ayalon et al., 1998; Mickler et al., 2004; Cruz et al., 2005) but opportunities for vital longer comparisons, which will provide a more holistic view of the effects of changing precipitation and temperature patterns, are very limited because long precipitation isotope records exist for relatively few localities (e.g. those available in the GNIP data base IAEA/WMO, 2004). Long instrumental climate records are far more widely available and Treble et al. (2005a) showed that a modern speleothem that grew between 1911 and 1992 in Moondyne Cave, SW Australia preserved seasonal cycles in $\delta^{18}$O but the decadal trends in $\delta^{18}$O and $\delta^{13}$C were more difficult to reconcile with observed changes in temperature or precipitation. Observation of seasonality in the speleothem isotopic record (Treble et al., 2005a; Mattey et al., 2005; Johnson et al., 2006) highlights the importance of understanding causes of seasonal components in the speleothem isotopic signal and provides opportunities for vital comparisons with instrumental records at inter-annual resolution.

Validation of speleothem climate proxies ideally requires a set of criteria and conditions that are not always possible to meet. A cave site at or very near to a location where a long instrumental record has been kept is pre-requisite to avoid bias caused by potentially significant local differences in temperature and rainfall patterns. Active speleothem growth needs to be at a site within the cave which has microphysical conditions that are not conducive to adverse isotopic fractionation, with a rate of calcite growth fast enough to produce annual laminae that are thick enough for sampling at sub-annual resolution. Knowledge of the hydrological response of seepage water to seasonal rainfall patterns is needed to know timescales of water storage and mixing in the karst aquifer (Tooth and Fairchild, 2003). Finally, a precise age model is required to correlate the speleothem $\delta^{18}$O time series with the climate record at the inter-annual scale.

Cave sites on the Gibraltar peninsula meet the requirements specified above and provide a unique opportunity to calibrate actively growing speleothem $\delta^{18}$O with one of the longest available precipitation isotopes and instrumental climate records. Here we report fabric-correlated cycles in high resolution stable isotope and trace element time series, which, in conjunction with cave monitoring data, show that the cycles are unequivocally related to seasonal changes in cave microclimate and hydrology. The seasonally resolved time series provide an oxygen isotope proxy record of winter precipitation that is accurately tied to calendar years by counting cycles from the time of collection. The age model is confirmed by location of the atmospheric $^{14}$C bomb carbon peak. These data provide a robust relationship between speleothem calcite fabrics, seepage waters and precipitation at seasonal resolution over a 50 year period and, to date, the longest possible inter-annual

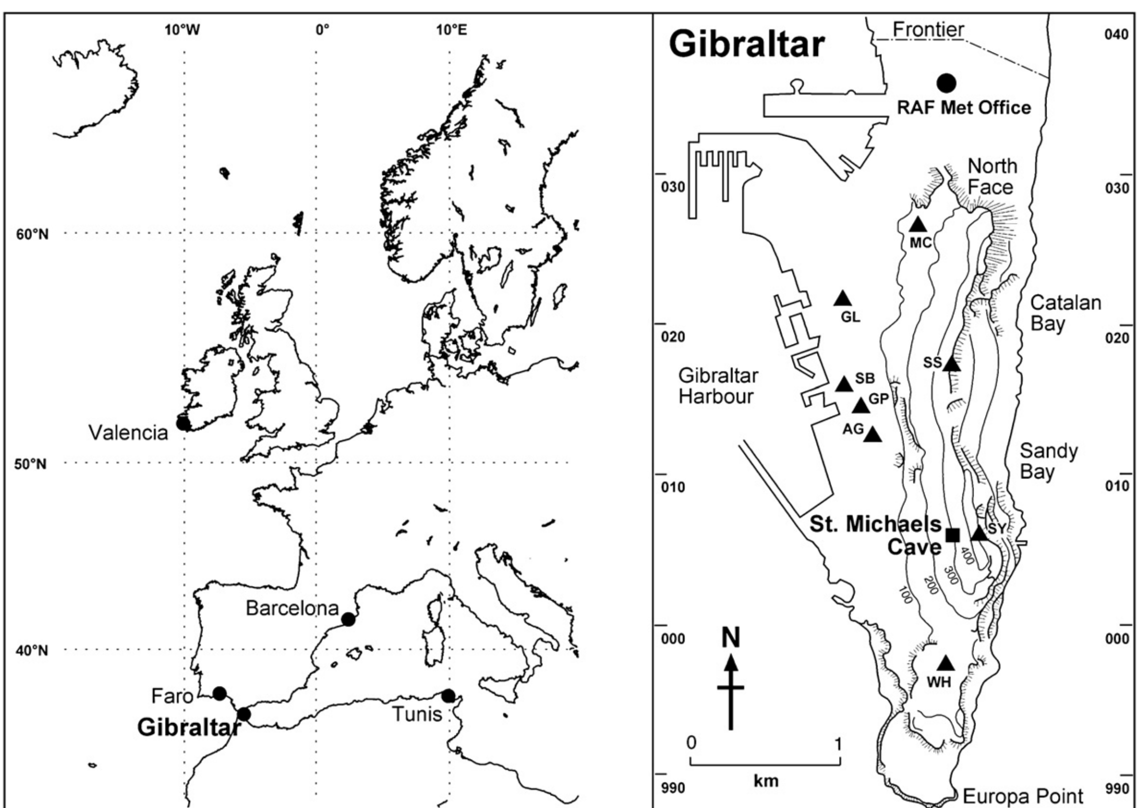


Fig. 1. Left: Location of Gibraltar and the maritime GNIP sites where more than 20 years of precipitation isotope data are available (IAEA/WMO, 2004). Right: Location map of St. Michaels Cave, the RAF Met Office and nearby historic weather station sites (triangles) with 1000 m UTM grid co-ordinates. Historic locations from Wheeler (2006); MC Moorish Castle, GL Garrison Library, SS Signal Station, SB South Bastion, GP Grand Parade, AG Alameda Gardens, SY Spyglass Battery, Windmill Hill.