Deciphering intra-decadal climate variations in the Central Mediterranean area during the Last Interglacial using speleothems

THE UNIVERSITY OF MELBOURNE

ANDREA COLUMBU[1*], RUSSELL DRYSDALE[1], JON WOODHEAD[2], JOHN HELLSTROM[2], JO DE WAELE[3]

[1] Department of Resource Management and Geography, University of Melbourne, VIC, 3010, Australia [2] School of Earth Sciences, The University of Melbourne, Parkville, VIC 3010, Australia [3] Department of Biological, Geological and Environmental Sciences, Via Zamboni 67, 40127 Bologna, Italy. *acolumbu@student.unimelb.edu.au

INTRODUCTION

The Last Interglacial (LIG) is the most recent period of the Earth climatically comparable with today, in terms of temperature, ice sheet extent, global sea level and atmospheric CO_2 concentration (1, 2, 3). Some aspects of the climate of this stage still appear poorly understood, such as the short-scale rainfall vs temperature variability. The North Atlantic Oscillation (NAO) is the main atmospheric pressure system controlling the timing, intensity and direction of westerly winds, and distribution of moisture and heat across the Mediterranean area. NAO has different cycles of variation, from 2 to 130 years (4). Identifying the decadal to intra-decadal climate variation during the LIG in the central Mediterranean and evaluating the presence of NAO-like fluctuations are among the main aims of my PhD study; the 1st year oxygen and carbon stable isotopes and dating results are proposed in this session for a well laminated Central Italian Flowstone (RTf).

STUDY AREA & CLIMATE

11 km of cave tunnels developed in 5 distinguished topographic levels, over an altitudinal range of 247 m, forms the Re Tiberio cave system, carved in the Tondo Mountain, around 40 km east of Bologna, Emilia Romagna Region (North Italy) (Figure 1). The host rock is the Messinian gypsum belonging to the well-known *Gessoso-Solfifera Formation*, now called the *Vena del Gesso Formation* (5, 6, 7), outcropping widely in the northern flank of the Apennines piedmont.
The area (44.2° N) is exposed to mid-latitude climate variability, primarily governed by the NAO and associated with secondary interconnection patterns (8, 9, 10). From 1961 to 2005 the average annual rainfall was 830,7 mm, mainly prevailing in autumn. The isotopic values of precipitation varies between -7‰ and -8‰ relative to SMOW international standard (11).

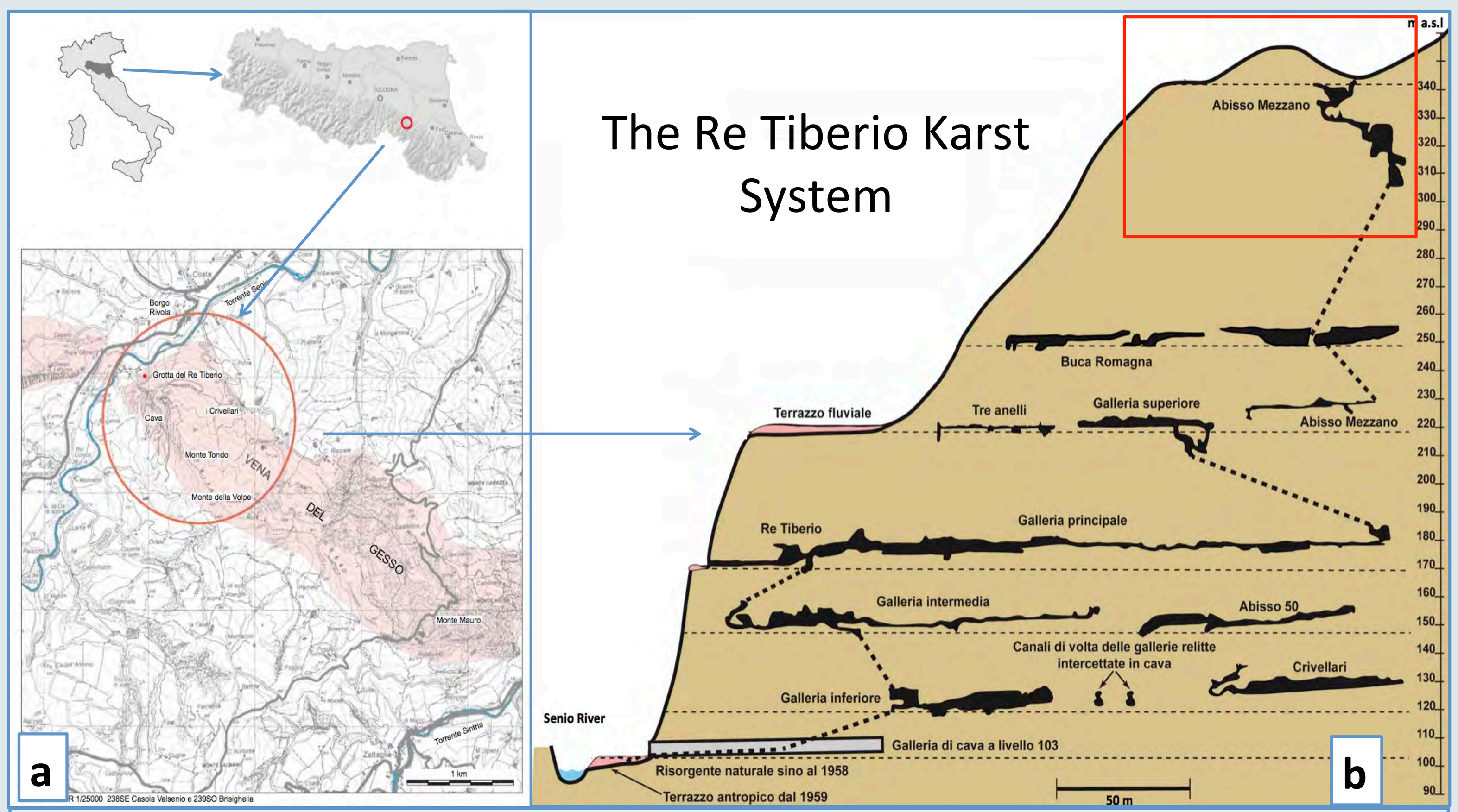
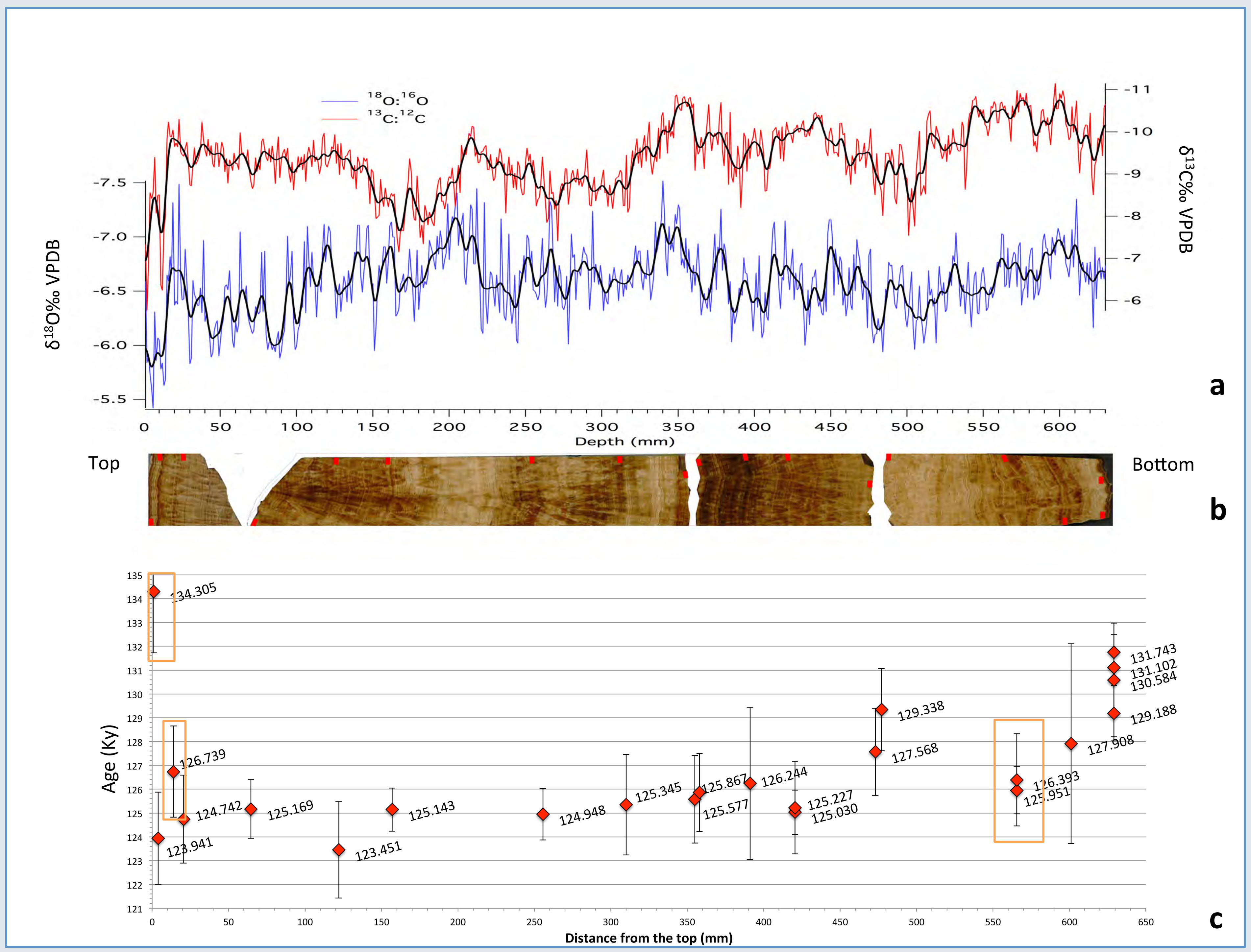


Figure 1, the area of study. a) Emilia Romagna region and cave site. The pink shadow indicates the gypsum karst area. b) Re tiberio karst system. The red square indicates the provenance of the studied flowstone (RTf).



Sample ID	Depth (mm)	U ppb	$^{230}Th/^{238}U$	$^{234}U/^{238}U$	$^{232}U/^{238}U$	$^{230}Th/^{232}Th$	*Age	2se (Ky)	error %
RT-D4	*1*	*861*	*0.6780*	*0.9582*	*0.011264*	*60.2*	*134.305*	*2.578*	*1.92*
RT-D3	4	1899	0.6484	0.9606	0.000684	947.6	123.941	1.940	1.56
RT-D2	*14*	*1406*	*0.6538*	*0.9577*	*0.000828*	*789.5*	*126.739*	*1.913*	*1.51*
RT-D1	21	1764	0.6461	0.9549	0.000682	947.8	124.742	1.850	1.48
RT-C6	65	972	0.6450	0.9529	0.000215	3003.7	125.169	1.229	0.98
RT-C5	122	1669	0.6389	0.9505	0.000250	2551.6	123.451	2.023	1.64
RT-C4	157	1619	0.6422	0.9494	0.000295	2175.9	125.143	0.911	0.73
RT-C3	256	3127	0.6472	0.9565	0.000098	6605.7	124.948	1.079	0.86
RT-C2	310	1748	0.6498	0.9579	0.000075	8677.3	125.345	2.109	1.68
RT-C1	355	1004	0.6562	0.9654	0.000599	1095.4	125.577	1.845	1.47
RT-B5	358	1068	0.6541	0.9618	0.000517	1265.7	125.867	1.641	1.30
RT-B4	391	1797	0.6479	0.9524	0.000125	5174.3	126.244	3.200	2.53
RT-B3	421	3238	0.6506	0.9603	0.000442	1472.1	125.030	0.935	0.75
RT-B2	421	1699	0.6514	0.9601	0.000425	1532.3	125.227	1.942	1.55
RT-B1	473	934	0.6541	0.9562	0.000239	2732.7	127.568	1.828	1.43
RT-A8	477	883	0.6560	0.9525	0.000666	985.3	129.338	1.724	1.33
RT-A7	566	1770	0.6490	0.9548	0.001019	637.1	125.951	0.990	0.79
RT-A6	*566*	*1443*	*0.6454*	*0.9482*	*0.001003*	*643.5*	*126.393*	*1.936*	*1.53*
RT-A5	*601*	*1582*	*0.6531*	*0.9491*	*0.007482*	*87.3*	*127.908*	*4.192*	*3.28*
RT-A4	629	1023	0.6558	0.9446	0.000848	773.6	131.743	0.752	0.57
RT-A3	629	848	0.6541	0.9446	0.000657	994.9	131.102	1.872	1.43
RT-A2	629	/	0.6508	0.9463	0.001092	595.8	129.188	1.160	0.90
RT-A1	629	1483	0.6542	0.9459	0.000454	1440.3	130.584	2.386	1.83

Figure 2, preliminary results. a) O (blue) and C (red) stable isotopes record. b) The Re tiberio flowstone (RTf); red squares are the dating points. c) Preliminary age-depth model. The table reports ages, associated errors and geochemical properties of the calcite. Ages in italic are considered unreliable. The orange box highlights incongruities in the age-depth model, maybe due to the presence of detrial material or re-opened geochemical system.

DISCUSSION

U-Th dating analysis indicate that RTf grew between 131.7±0.8 and 123.9±1.9 ky BP, when full interglacial conditions were reached in Southern Europe (16). The growth rate appears relatively lower in the first half and faster in the second, with an average of 92 mm/ka. One probable hiatus is observable at 480 mm from the top (Figure 2).
Stable isotopes analysis reveals that $\delta^{18}O$ varies from -5.42‰ to -7.52‰ and $\delta^{13}C$ from -5.76‰ to -11.15‰ referring to VPDB international standard (Figure 2). Despite the moderate shift in the absolute value, the stable isotope curve demonstrates a remarkable high frequency variation, in the order of ±0.6‰ for the $\delta^{18}O$. A preliminary interpretation of this trend could involve the rainfall amount effect, commonly anticorrelated with $\delta^{18}O$ calcite value (17, 18). It implies that high (low) amounts of rain decrease (increase) the stable oxygen isotope ratio, as shown in nearby Tana che Urla and Corchia Cave (19, 20, 21). Furthermore, variation in the seasonal distribution of rainfall and provenance/air mass history of moisture may have a key role in $\delta^{18}O$ changes. In this case, the RTf decadal to intra-decadal isotopic pattern may be the response of NAO-driven atmospheric circulation variation, providing interesting data for the study of palaeoNAO mode and tempo.
At this stage of the project, ocean-surface water $\delta^{18}O$ changes or other atmospheric effects are reasonably excluded in the interpretation of $\delta^{18}O$ behavior, considering that they usually act on different (longer) timescales. Conversely, oscillations in average temperatures might have influenced the paleoclimatic signature of the flowstone, in an independent way or associated with the hydrological factors. However, the cave site monitoring part of this project, involving rainfall isotope patterns and their transfer into the cave seepage waters and modern speleothem calcite, will verify these proposed mechanisms driving the MIS 5e isotopic variations. Finally, other proxy data analysis, such as trace elements and fluid inclusions, will add important information on the multiannual hydrological variations in the system.

MATERIALS & METHODS

A ~65 cm long carbonate flowstone (RTf) was sampled in the upper level of the cave system. It shows an impressive well preserved layering, probably given by annual climate oscillations.
15 subsamples were dated using the U-Th method following the procedure set out in (12), modified as described in (13). All U and Th isotope ratios were determined simultaneously using a Nu Instruments Plasma MC-ICP-MS. Corrected U-Th ages were determined for all samples using the 230Th and 234U decay constants of (14) and equation 1 of (15).
For oxygen and carbon stable isotopes analysis 631 carbonate powder samples were extracted using a 1-mm diameter microdrilling bit, with a 1 mm constant spacing, perpendicular to the visible growth layering then analyzed on a AP2003 mass spectrometer using New1, NBS19, NBS18 and New12 as procedural standards.
All the analyses were performed in the laboratories of The University of Melbourne.

CONCLUSION

The precisely date fast growing RTf seems to record decadal to intradecadal climate oscillation of the last interglacial. High frequency stable isotopes variations might be linked to changes in rainfall patterns and hydrogeological circulation at the time of calcite deposition. Considering that the climate of the area of study is governed by the NAO, RTf proxy data might reflect the variation of this atmospheric system during the LIG. Higher temporal-spatial resolution analysis associated with the ongoing monitoring of the cave site will confirm/reject this theory, providing new clues for deciphering the poorly understood last interglacial short-term climate variation.

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